THE EFFECTS OF FORESTS
ON SNOW COVER

INTEGRATED WILDLIFE INTENSIVE FORESTRY RESEARCH

Province of British Columbia

A cooperative project between the Ministries of Environment and Forests

THE EFFECTS OF FORESTS ON SNOW COVER
an annotated bibliography

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INTRODUCTION

The objective of this project was to gather and annotate the literature relevant to interactions between trees and snow. The snow literature is characterized by being widely dispersed in journals of several disciplines and by being directly relevant primarily to particular hydrological, meteorological, ecological, or forestry concerns. A key to this literature is needed to facilitate current research on the production of winter range for black-tailed deer and Roosevelt elk in the deep snow areas on Vancouver Island. The material collated is also applicable to snow-related research throughout British Columbia.

KEYWORDS

The keywords are a compromise between close delineation and simplicity. Thirty-four terms are used. These terms are presented in three broad groups:

1. Forest stand and site characteristics
2. Snow measurements
3. Geographical location.

In the key-wording each broad group is separated by a solidus (/). Examples:

i) (Forest Openings, Shade/Snowpack, Snowmelt/U.S. West Coast)
ii) (Canopy Cover/Snow Accumulation, Snowmelt/General)
iii) (/Snow Interception/Arctic-Subarctic)

Example iii) is a general discussion of qali (snow that collects on trees) and does not treat particular stand characteristics - thus, there is no appropriate keyword for the first broad group. The lack of stand distinctions is indicated by the absence of a keyword before the first solidus.

Clarification of terms

I. Forest stand and site characteristics: fourteen terms are used. Some (e.g., aspect, slope, elevation, temperature, wind, shade) require no clarification. The intended meaning of other keyword terms follows:

General: either the treatment encompasses a wide variety of stand and site types and posits a general relationship; or the treatment assumes that the relationship discussed is general.

Forest cover: no measure of the forest cover is provided; such publications usually compare forested areas with unforested areas.

Forest openings: most publications with this keyword term have examined forest openings of different sizes. Discussion of the openings may use the abbreviation TH for tree height; for example, the openings may be described as 2 TH long and 0.5 TH wide. Tree height (TH) usually is the mean tree height of adjacent forest stands.

Forest density: the publication treats forest density either in arbitrarily defined classes or on the basis of stems ha^{-1} or basal area.

Canopy cover: some measure of the degree of canopy or crown cover or closure is presented or discussed.

Forest type: is used as a keyword when different kinds of forest

were compared; it is a general term intended to include age differences, comparisons between conifer and hardwood forests, or between age structures resulting from different silvicultural practices.

Forest composition: is a more specific term than forest type and is limited to comparisons involving tree species.

Crown characteristics: is used when publications describe such attributes of the crown as form class, length, width, branching habit, etc.

II Snow measurements: the kinds of snow measurements reported are described by 8 terms of which few need clarification.

- snowpack
- snowmelt
- snowdepth
- snow interception
- snow density
- snow deposition (includes snow 'migration' and 'delivery')
- snow hardness
- snow accumulation

III Geographical location: these keywords describe the location of the study and in the following table are grouped by geographical affinity. For example, 'U.S. West Coast' and 'Canadian West Coast' occur in adjacent columns. The categories are wide to keep the number of terms small; 11 terms are used.

General: indicates either a review paper covering a large geographical range or a level of treatment that is assumed valid independent of its location.

U.S. Mountains: the western Cordillera, usually the Rocky Mountains.

Canadian Mountains: the Canadian portion of the Cordillera, usually the Rocky Mountains.

The remaining terms are straightforward and include: Eastern U.S., Canadian Boreal, U.S. West Coast, Canadian West Coast, Arctic-Subarctic, U.S.S.R., Europe, Asia.

IV Abbreviations:

TH = tree height; used to describe dimensions of forest openings. Usually refers to the mean tree height of the adjacent stand.

SWE = snow water equivalent; the amount of water present in a given snow pack. Either computed from snow density measurements, or a density of 0.10 g cm^{-3} is assumed.

CROSS-REFERENCE TABLE

Keyword

	Annotated Reference Number											
	1	2	3	4	5	6	7	8	9	10	11	12
General							X					
Forest Cover	X											
Forest Openings	X	X	X	X		X			X	X	X	
Forest Density			X							X		
Canopy Cover				X					X	X	X	
Shade	X			X	X				X			
Forest Type												
Forest Composition											X	
Crown Characteristics												
Aspect				X						X	X	
Elevation				X							X	
Slope				X						X	X	
Temperature				X								
Wind				X		X						
Snowpack	X	X	X			X			X	X	X	
Snowmelt	X	X	X		X	X	X		X	X	X	
Snow Depth												
Snow Interception				X			X					
Snow Density												
Snow Deposition							X					
Snow Hardness												
Snow Accumulation				X								
General							X					
U.S. Mountains	X	X	X	X		X			X	X	X	
Canadian Mountains												
Eastern U.S.												
Canadian Boreal												
U.S. West Coast					X							
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe												
Asia												
	1	2	3	4	5	6	7	8	9	10	11	12

CROSS-REFERENCE TABLE (continued)

Keyword

	Annotated Reference Number											
	13	14	15	16	17	18	19	20	21	22	23	24
General				X					X			X
Forest Cover								X	X			
Forest Openings		X				X	X					
Forest Density	X					X						
Canopy Cover										X		X
Shade										X		
Forest Type												
Forest Composition					X						X	X
Crown Characteristics					X						X	
Aspect							X					X
Elevation								X				X
Slope												X
Temperature								X		X		X
Wind												X
Snowpack		X		X		X	X					X
Snowmelt	X	X				X	X	X		X		X
Snow Depth	X	X							X			X
Snow Interception					X						X	X
Snow Density									X			X
Snow Deposition												
Snow Hardness									X			
Snow Accumulation												X
General				X	X							X
U.S. Mountains						X	X	X		X		
Canadian Mountains												
Eastern U.S.	X	X										
Canadian Boreal												
U.S. West Coast												
Canadian West Coast									X			
Arctic-Subarctic												
USSR											X	
Europe												
Asia												
	13	14	15	16	17	18	19	20	21	22	23	24

Annotated Reference Number

Keyword	25	26	27	28	29	30	31	32	33	34	35	36
General						X			X			
Forest Cover												
Forest Openings	X		X				X			X		
Forest Density												
Canopy Cover			X							X		
Shade												
Forest Type	X											
Forest Composition			X									
Crown Characteristics			X							X		
Aspects	X											
Elevation												X
Slope												
Temperature												
Wind												
Snowpack			X				X			X		X
Snowmelt			X				X			X		X
Snow Depth	X									X		
Snow Interception						X						
Snow Density												
Snow Deposition												
Snow Hardness												
Snow Accumulation												
General						X			X			
U.S. Mountains			X				X			X		X
Canadian Mountains												
Eastern U.S.												
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR	X											
Europe												
Asia												
	25	26	27	28	29	30	31	32	33	34	35	36

Keyword

	Annotated Reference Number											
	37	38	39	40	41	42	43	44	45	46	47	48
General												
Forest Cover												
Forest Openings				X	X			X	X			
Forest Density						X			X			
Canopy Cover		X					X		X	X	X	X
Shade												
Forest Type												
Forest Composition									X			
Crown Characteristics		X										
Aspects												
Elevation								X				
Slope										X		
Temperature												
Wind	X											
Snowpack			X		X			X				X
Snowmelt			X	X	X		X	X			X	
Snow Depth						X			X			
Snow Interception	X	X								X		
Snow Density												
Snow Deposition		X										
Snow Hardness									X			
Snow Accumulation											X	
General												
U.S. Mountains			X		X		X	X				X
Canadian Mountains												
Eastern U.S.				X		X			X		X	
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe	X	X								X		
Asia												
	37	38	39	40	41	42	43	44	45	46	47	48

Keyword

	Annotated Reference Number											
	49	50	51	52	53	54	55	56	57	58	59	60
General												
Forest Cover												
Forest Openings			X				X	X				X
Forest Density				X		X			X			
Canopy Cover	X				X			X			X	
Shade												
Forest Type			X						X			
Forest Composition		X								X		
Crown Characteristics										X		
Aspects						X					X	
Elevation					X			X				
Slope						X					X	
Temperature											X	
Wind												
Snowpack	X	X				X		X			X	
Snowmelt		X	X			X			X		X	X
Snow Depth			X				X		X			
Snow Interception			X	X				X	X	X		
Snow Density					X		X		X			
Snow Deposition								X				X
Snow Hardness												
Snow Accumulation												
General												
U.S. Mountains	X		X	X	X	X					X	X
Canadian Mountains												
Eastern U.S.		X										
Canadian Boreal												
U.S. West Coast										X		
Canadian West Coast								X				
Arctic-Subarctic												
USSR												
Europe							X					
Asia												
	49	50	51	52	53	54	55	56	57	58	59	60

Keyword

	Annotated Reference Number											
	61	62	63	64	65	66	67	68	69	70	71	72
General						X			X	X	X	
Forest Cover												
Forest Openings	X	X	X									
Forest Density												X
Canopy Cover				X				X				
Shade	X						X					
Forest Type												
Forest Composition												
Crown Characteristics			X									
Aspect				X			X					
Elevation				X			X					
Slope							X					
Temperature							X		X	X		
Wind		X										
Snowpack			X	X		X				X		X
Snowmelt	X			X							X	
Snow Depth								X		X		
Snow Interception							X	X			X	
Snow Density									X	X		
Snow Deposition	X	X										
Snow Hardness									X			
Snow Accumulation												
General							X		X			
U.S. Mountains	X	X	X	X								
Canadian Mountains											X	X
Eastern U.S.						X		X				
Canadian Boreal										X		
U.S. West Coast												
Canadian West Coast											X	
Arctic-Subarctic												
USSR												
Europe												
Asia												
	61	62	63	64	65	66	67	69	69	70	71	72

Annotated Reference Number

Keyword	73	74	75	76	77	78	79	80	81	82	83	84
General									X			
Forest Cover												
Forest Openings		X		x	X	X	X	X			X	
Forest Density	X		X					X			X	
Canopy Cover											X	X
Shade												
Forest Type		X										
Forest Composition												
Crown Characteristics												
Aspect	X	X									X	
Elevation	X										X	
Slope	X											
Temperature												
Wind												
Snowpack	X	X	X	X	X	X	X				X	X
Snowmelt		X		X	X	X		X			X	
Snow Depth		X										
Snow Interception								X	X			
Snow Density												
Snow Deposition								X				
Snow Hardness												
Snow Accumulation												
General									X			
U.S. Mountains						X	X	X			X	
Canadian Mountains	X	X	X	X	X							
Eastern U.S.												
Canadian Boreal												
U.S. West Coast												X
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe												
Asia												
	73	74	75	76	77	78	79	80	81	82	83	84

Keyword

	Annotated Reference Number											
	85	86	87	88	89	90	91	92	93	94	95	96
General								X				
Forest Cover												
Forest Openings	X						X	X	X	X	X	
Forest Density				X								
Canopy Cover		X	X			X	X	X				
Shade												
Forest Type							X					
Forest Composition												
Crown Characteristics												
Aspects										X		
Elevation												
Slope	X						X		X			
Temperature									X			X
Wind												
Snowpack				X		X	X			X	X	
Snowmelt	X			X		X	X	X		X	X	
Snow Depth		X						X	X			
Snow Interception			X					X				X
Snow Density		X										
Snow Deposition										X		
Snow Hardness												
Snow Accumulation	X						X					
General		X	X									
U.S. Mountains	X			X			X	X	X	X	X	
Canadian Mountains												
Eastern U.S.						X						
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe												X
Asia												
	85	86	87	88	89	90	91	92	93	94	95	96

CROSS-REFERENCE TABLE (continued)

Keyword

	Annotated Reference Number											
	97	98	99	100	101	102	103	104	105	106	107	108
General												
Forest Cover								X			X	
Forest Openings	X	X		X	X			X	X	X		
Forest Density												
Canopy Cover							X		X			X
Shade												
Forest Type												
Forest Composition					X							
Crown Characteristics				X								
Aspects								X				
Elevation					X							X
Slope												
Temperature								X				
Wind												
Snowpack	X											
Snowmelt	X				X			X	X			
Snow Depth					X			X				X
Snow Interception		X		X	X		X		X			
Snow Density												
Snow Deposition									X		X	
Snow Hardness												
Snow Accumulation										X		
General		X							X			
U.S. Mountains	X			X	X		X	X			X	
Canadian Mountains										X		
Eastern U.S.												
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												X
Arctic-Subarctic												
USSR												
Europe												
Asia												
	97	98	99	100	101	102	103	104	105	106	107	108

CROSS-REFERENCE TABLE (continued)

Keyword

	Annotated Reference Number											
	109	110	111	112	113	114	115	116	117	118	119	120
General							X					
Forest Cover												
Forest Openings	X	X	X									
Forest Density											X	
Canopy Cover		X	X						X	X		X
Shade												
Forest Type												
Forest Composition	X		X		X						X	
Crown Characteristics				X	X							X
Aspects									X	X		
Elevation										X		
Slope									X	X		
Temperature										X		
Wind						X						
Snowpack			X						X		X	
Snowmelt	X	X	X				X			X	X	
Snow Depth			X									
Snow Interception	X		X	X	X							X
Snow Density		X										
Snow Deposition		X				X				X		
Snow Hardness												
Snow Accumulation												
General		X										
U.S. Mountains			X	X					X	X	X	X
Canadian Mountains												
Eastern U.S.	X											
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR					X	X	X					
Europe												
Asia												
	109	110	111	112	113	114	115	116	117	118	119	120

Keyword

	Annotated Reference Number											
	121	122	123	124	125	126	127	128	129	130	131	132
General												
Forest Cover												
Forest Openings	X	X						X	X			X
Forest Density	X		X									
Canopy Cover			X	X								
Shade										X		
Forest Type												
Forest Composition			X							X	X	
Crown Characteristics				X								
Aspects							X					X
Elevation												
Slope							X					
Temperature												
Wind												
Snowpack	X		X	X			X	X	X		X	
Snowmelt	X	X	X	X			X	X	X	X		
Snow Depth												X
Snow Interception		X		X								
Snow Density											X	
Snow Deposition										X		
Snow Hardness												
Snow Accumulation												
General											X	
U.S. Mountains	X						X	X	X			
Canadian Mountains												X
Eastern U.S.		X	X	X						X		
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe												
Asia												
	121	122	123	124	125	126	127	128	129	130	131	132

Keyword

	Annotated Reference Number											
	133	134	135	136	137	138	139	140	141	142	143	144
General										X		
Forest Cover				X								
Forest Openings	X					X					X	X
Forest Density						X						X
Canopy Cover	X	X	X		X	X					X	
Shade												
Forest Type					X							
Forest Composition									X		X	
Crown Characteristics					X			X	X		X	
Aspects		X										
Elevation		X	X									
Slope												
Temperature								X	X			
Wind								X	X			
Snowpack		X	X									X
Snowmelt	X					X						X
Snow Depth				X								
Snow Interception							X	X	X	X	X	
Snow Density												
Snow Deposition												
Snow Hardness												
Snow Accumulation												
General		X				X		X	X	X	X	
U.S. Mountains					X							X
Canadian Mountains												
Eastern U.S.												
Canadian Boreal												
U.S. West Coast	X			X								
Canadian West Coast												
Arctic-Subarctic												
USSR												
Europe												
Asia												
	133	134	135	136	137	138	139	140	141	142	143	144

Keyword

	Annotated Reference Number											
	145	146	147	148	149	150	151	152	153	154	155	156
General												
Forest Cover										X		
Forest Openings					X		X					X
Forest Density			X		X			X				
Canopy Cover			X	X		X	X	X				
Shade												
Forest Type		X	X						X			
Forest Composition			X	X					X			
Crown Characteristics			X									
Aspects						X	X	X			X	
Elevation						X	X	X				
Slope								X				
Temperature												
Wind											X	
Snowpack					X	X	X					X
Snowmelt					X			X				X
Snow Depth				X					X			X
Snow Interception		X	X							X	X	
Snow Density												
Snow Deposition												
Snow Hardness												
Snow Accumulation												
General												
U.S. Mountains					X	X	X	X				X
Canadian Mountains												
Eastern U.S.			X						X			
Canadian Boreal												
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic										X		
USSR		X		X								
Europe											X	
Asia												
	145	146	147	148	149	150	151	152	153	154	155	156

Annotated Reference Number

Keyword	157	158	159	160	161	162	163	164	165	166	167	168
General												
Forest Cover	X											
Forest Openings		X										
Forest Density								X				
Canopy Cover												X
Shade												
Forest Type	X											
Forest Composition												X
Crown Characteristics			X	X	X							
Aspects												
Elevation						X						
Slope												
Temperature											X	
Wind			X								X	
Snowpack		X				X		X				
Snowmelt		X	X				X					
Snow Depth		X										X
Snow Interception	X		X	X	X			X	X		X	
Snow Density		X										
Snow Deposition												
Snow Hardness												
Snow Accumulation												
General			X				X					
U.S. Mountains	X			X	X							
Canadian Mountains						X						
Eastern U.S.		X										
Canadian Boreal												X
U.S. West Coast												
Canadian West Coast						X						
Arctic-Subarctic												
USSR												
Europe								X	X			
Asia											X	
	157	158	159	160	161	162	163	164	165	166	167	168

Keyword	Annotated Reference Number											
	169	170	171	172	173	174	175	176	177	178	179	180
General												
Forest Cover												
Forest Openings		X		X		X						X
Forest Density			X									
Canopy Cover						X			X	X		
Shade												
Forest Type		X										
Forest Composition	X	X				X		X				X
Crown Characteristics		X			X						X	
Aspects				X								
Elevation												
Slope												
Temperature							X					
Wind												
Snowpack		X		X	X	X				X		X
Snowmelt		X	X	X	X	X		X				X
Snow Depth	X											
Snow Interception		X					X	X	X		X	
Snow Density												
Snow Deposition												
Snow Hardness												
Snow Accumulation												
General									X			
U.S. Mountains	X	X	X		X							
Canadian Mountains				X		X						
Eastern U.S.								X				X
Canadian Boreal										X		
U.S. West Coast												
Canadian West Coast												
Arctic-Subarctic												
USSR							X					
Europe												
Asia											X	
	169	170	171	172	173	174	175	176	177	178	179	180

CROSS-REFERENCE TABLE (continued)

Keyword

	Annotated Reference Number									
	181	182	183	184	185	186	187	188	189	190
General									X	
Forest Cover										X
Forest Openings	X	X	X							X
Forest Density					X					
Canopy Cover			X	X				X		
Shade										
Forest Type										
Forest Composition										X
Crown Characteristics										
Aspects		X				X				
Elevation						X				
Slope		X				X				
Temperature		X				X				
Wind										
Snowpack		X			X					X
Snowmelt	X		X	X	X					X
Snow Depth		X								
Snow Interception								X	X	
Snow Density										
Snow Deposition										
Snow Hardness										
Snow Accumulation				X						
General									X	
U.S. Mountains	X		X	X	X					
Canadian Mountains										
Eastern U.S.										
Canadian Boreal										
U.S. West Coast		X								
Canadian West Coast								X		
Arctic-Subarctic										
USSR										
Europe										X
Asia										
	181	182	183	184	185	186	187	188	189	190

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1 Anderson, H.W. 1956. Forest-cover effects on snow pack accumulation and melt, Central Sierra Snow Laboratory. Trans. Amer. Geophys. Union 37: 307-312.

(Shade, Forest Openings/Snowpack, Snowmelt/ U.S. Mountains)

Snowpack accumulation and melt were related to amount of shade from trees to the south and shielding from trees to the north of snow measurement points. Shading was expressed as shade duration multiplied by solar incidence in the open. Shielding was expressed as ratio of TH (tree height) to distance to trees. Shading and shielding explain 56% of the variation in SWE. The relation between April 1 snowpack and shade is curvilinear with maximum pack at a point where shade is 65% and no trees to the north. On average, SWE was 11 inches less in dense forest than in the open. Shade was twice as important a factor as shielding. Forty percent of melt rate was explained by the two variables with shade being much more important. The effects of cutting the forest in certain patterns were estimated.

2 Anderson, H.W. 1960. Prospects for affecting the quantity and timing of water yield through snowpack management in California. Proc. Western Snow Conf. 28: 44-50.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

A review of cooperative snow management studies in California from 1956-1960. Clear-cutting increases both the snowpack and the melt rate. Average SWE differences are stated. Strip cutting increases the snowpack without increasing the melt as much as does clear-cutting. Whereas strips 1 TH in width usually retard melt most, the last snow is found in the forest and in strips 1/2 TH in width. Block cuts 1 TH square store more water than do strip cuts. Selective cutting increases both snow accumulation and melt by opening the canopy.

3 Anderson, H.W. 1960. Research in management of snowpack watersheds for water yield control. J. Forestry 58: 282-284.

(Forest Openings, Forest Density/Snowpack, Snowmelt/ U.S. Mountains)

A review of California snow research. SWE is given under various forest canopy densities, showing dense forests accumulate the least snow and forest openings the most. The "wall-and-step" forest cutting is described for

maximal snow accumulation and delay of melt.

4 Anderson, H.W. 1967. Snow accumulation as related to meteorological, topographic, and forest variables in Central Sierra Nevada, California. Intl. Assoc. Scientific Hydrology 76: 215-224.

(Forest Openings, Canopy Cover, Shade, Aspect, Elevation, Slope, Temperature, Wind/Snow Interception, Snow Accumulation/U.S. Mountains)

Adapted from author's abstract: snow accumulation at individual points in coniferous forest and openings in forests (1.7 to 7.5 TH) was studied by selecting 16 periods in the winter of 1957-58 under different meteorological conditions. Wide differences in topography and forest conditions were obtained by selection of 250 points from 1,300 available. Snow accumulation was the difference in water equivalent of the snowpack between measurements. Meteorolological variables included functions of clouds, wind, humidity, temperature, and precipitation. Forest variables included indexes of shade, back radiation, interception, cold air drainage, and shelter from the wind. Topography was expressed in terms of solar energy received and exposure to prevailing winds. The factors related to snow accumulation were studied by reduced rank procedure of principal components, principal axis, canonical, and alpha factoring with varimax rotation of the factors. The best regressions relating the variables to snow accumulations arose from principal components analysis when highly correlated variables were included. Snow accumulation depended strongly on combinations of meteorological and forest variables, and on forest-meteorological interactions. Interception of snow, as indexed by the canopy over the point, averaged 10 per cent of the precipitation. Snow accumulation in forest openings, forest margins, and in large areas of uniform forest had different relations to meteorological and topographic variables. Forest shade and back radiation from trees were most important on high energy south slopes. Considerable useful data presented.

5 Anderson, H.W. 1969. Snowpack management. Pages 27-40 in: Snow., Oregon St. Univ., Water Resour. Inst., Seminar WR 011.69.

(Shade/Snowmelt/U.S. West Coast)

In a study of a 3-day, rainfall-snowmelt flood in Oregon, Anderson estimated that conifer forest shading reduced the melt rate by 40% (and flood flow by 10%). Not seen, cited from Anderson, Hoover and Reinhart (1976).

6 Anderson, H.W., and C.H. Gleason. 1959. Logging effects on snow, soil moisture, and water losses. Proc. Western Snow Conf. 27: 57-65.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

A study of the effect of various logging practices on snow accumulation and melt. Snow accumulation was greatest in forest openings. Open stands of various ages had almost as much snow as the openings. Spring melt rates were highest in the large openings. The maximum amount of snow in June was in the small openings. Snow immediately to the leeward of openings was less than snow in the openings or further into the forest. About one-half of the greater snow of the openings was "stolen" from the leeward forests. Cutting increased the snowpack relative to the forest; the amount of effect depended upon strip width. Commercial selection-cutting increased both snowpack and melt rates.

7 Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forests and water: Effects of forest management on floods, sedimentation and water supply. USDA For. Serv. Tech. Report PSW-18. 115 pp.

(General/Snowmelt, Snow Interception, Snow Deposition/ General)

A clearly-written review article that covers all hydrologic processes and a great variety of forest treatments. The portion discussing forestry:snow relationships is limited, but well presented. They conclude that mature conifers in western snowpack zones intercept 10 to 30% of the snowfall (p.8) and provide 5 examples (all treated in this bibliography). Table 6 summarizes results of 10 studies that documented increases in maximum SWE after cutting coniferous forest. Results are presented by forest type and cutting practice, including thinning. Seven of the 10 studies are included in this bibliography.

8 Anderson, H.W., and T.H. Pagenhart. 1957. Snow on forested slopes. Proc. Western Snow Conf. 25: 19-23.

(Keywords to come)

Not seen.

9 Anderson, H.W., R.M. Rice, and A.J. West. 1958. Forest shade related to snow accumulation. Proc. Western Snow Conf. 26: 21-31.

(Canopy Cover, Forest Openings, Shade/Snowpack,

Snowmelt/U.S. Mountains)

A three part study investigating the effects of forest cover on snow accumulation and melt in Canada. Part 1 deals with the effects of cover expressed as hemispherical cover and cover density. The study utilized six measurements on five snow courses over three years in the red fir forest type. At each sample point, the hemisphere was divided into parts by 15° of azimuth and 10° of vertical angles. At each intersection, distances to trees, through foliage and cover density was recorded. Only 3% of April 1 snowpack was explained by hemispherical cover and cover density. Hemispherical cover was a significant indicator of spring melt. Part 2 deals with shading effects. Around each point, the shade produced on the southern half was estimated. The forest to the north of each point was indexed according to tree height. Both indexes were significantly related to April 1 snowpack and spring snowmelt with shade more powerful than tree height. Curves predicting snowpack and snowmelt vs trees-to-north and shade are given. Part 3 is a multiple regression analysis relating snow water equivalent to 12 forest, meteorological, energy and joint variables. In total, 88% of the variation was explained. Forest variables were not particularly powerful.

10 Anderson, H.W., R.M. Rice, and A.J. West. 1958. Snow forest openings and forest stands. Proc. Soc. Am. For. 1958: 46-50.

(Forest Openings, Forest Density, Aspect, Slope, Canopy Cover/Snowpack, Snowmelt/U.S. Mountains)

Analysis of 57 snow courses incorporating 28 openings, forests of varying density and all aspects and slopes. In openings, greatest SWE's were found on downslope sides subject to cold air drainage. Within forest stands adjacent to openings, maximal accumulations were found to the southwest. Snow appears to have been 'stolen' from the northeast side. Forest margins had 5-8 inches less SWE than the openings. Minimum melt was found on the south side of the openings. Except for east slopes, Snowmelt was faster in the openings than in the adjacent forest. Openings 1-2 TH in width held snow the longest. Tables 2 and 3 present SWE's on April 22 and June 1 in 3 densities of forest on all aspects and various slopes. Maximal snow accumulations were in the least dense forests but melt was faster. Quamanigs were measured and found to be deepest on the north and east sides of trees.

11 Anderson, H.W., and A.J. West. 1966. Snow accumulation and melt in relation to terrain in wet and dry years. Proc. Western Snow Conf. 33: 73-82.

(Canopy Cover, Forest Openings, Elevation, Forest Composition, Aspect, Slope/Snowpack, Snowmelt/ U.S. Mountains)

A multi-variate analysis of local terrain effects on SWE in California. Elevational differences in SWE increased with progression of the winter. Dense forest (> 85% canopy cover) averaged 7.6 inches less snow than openings. Forests near openings had about 1 inch less than openings. Opening width had more effect on Snowpack in heavy snowfall years. Openings 4 TH in diameter trapped 3-3 1/2 inches more snow than 1 TH openings during wet years and only 1 inch more in dry years. Tree size and species had effects on SWE. Cold air drainage delayed snowmelt on the downhill side of openings and in the adjacent forest. Forest cover may affect SWE as much as 1/2 mile to the leeward. Thinning a dense forest (66% canopy cover) by 33% can increase the April 1 SWE by 5.7 inches 1/2 mile to the leeward. East slopes were equivlant to west slopes. When SWE was greater than 20 inches, the largest differences in Snowpack between north and south slopes occurred in the forest. In forests, openings, and forests near openings, maximum north-south differences occurred at SWE of 35 inches.

12 Ayer, G.R. 1961. Effect of forest cover on snowmelt runoff. Proc. Eastern Snow Conf. 4: 18-24.

(Keywords to come)

Not seen.

13 Bay, R.R. 1958a. Forest type affects snowpack. J. Soil and Water Conserv. 13(2): 129-130.

(Forest Density/Snow Depth, Snowmelt/Eastern U.S.)

A comparison of snow accumulation and melt in a brush-aspen type and in a red pine plantation (746 trees acre^{-1} and basal area of 94 ft^2 acre^{-1}). Snow depth and SWE were maximal in the aspen-brush type. The snow melted more quickly on aspen-brush type.

14 Bay, R.R. 1958b. Cutting methods affect accumulation and melt in black spruce stands. U.S.D.A. For. Serv. tech. Note. LS-523. 2 pp.

(Forest Openings/Snow Depth, Snowpack, Snowmelt/Eastern U.S.)

Black spruce was cut in five different patterns; a) a clearcut strip 66 ft wide and 396 ft long, b) a shelterwood cut leaving 51 ft^2 acre^{-1}, c) individual tree

selection leaving 75 ft^2 $acre^{-1}$, d) a one-half acre clearcut, and e) uncut at 132 ft^2 $acre^{-1}$. The order from most to least snow accumulation was d,a,b,c,and e. At the maximum, snow depths in the clearcuts were about 25 inches vs 13 in the uncut forest. The order of melt rate was d,b,c,a, and e. Cutting narrow east-west running strips seems to increase accumulation and retard melt.

15 Baldwin, H.I. 1956. The effect of forest on snow cover. Proc. Western Snow Conf. 24: 18-22.

(Keywords to come)

Not seen.

16 Beaumont, R.T. 1966. Snow accumulation. Proc. Western Snow Conf. 34: 3-6.

(General/Snowpack/General)

A superficial review of SWE measuring techniques.

17 Bennett, I. 1959. Glaze: its meteorology and climatology, geographical distribution and economic effects. U.S. Army Quartermaster Res. Engin. Center Techn. Rpt. EP-105. 224 pp.

(Crown Characteristics, Forest Composition/Snow Interception/General)

Hardwoods are more vulnerable to ice-loading than are conifers. This is because conifers have more resilient branches, smaller crowns, and a mechanically stronger branching habit.

Not seen - cited in Miller (1964).

18 Berndt, H.W. 1961. Influences of timber cutting on snow accumulation in the Colorado Front Range. USDA For. Serv., Rocky Mountain For. and Range Exp. Stat. Res. Note 58. 3 pp.

(Forest Density, Forest Openings/Snowmelt, Snowpack/ U.S. Mountains)

Six 4-acre plots were sampled in an uneven-aged stand on a north slope. Plots were then left uncut, selectively logged or clear-cut. Clearcutting increased SWE of pack by 49-52% whereas selective logging increased it 11-18%. Snowmelts were also increased as snow disappeared from all plots at about the same date.

19 Berndt, H.W. 1965. Snow accumulation and disappearance in lodgepole pine clearcut blocks in Wyoming. J. Forestry 63: 88-91.

(Forest Openings, Aspect/Snowpack, Snowmelt/ U.S. Mountains)

Only minor differences in snowpack were noted between clearcut blocks of 5, 10, and 20 acres. The peak SWE was 40% greater in the clearcuts than in the uncut forest. Snow disappearance was unaffected by clearcut size. Snow disappeared about 10 days earlier in clearcuts than in the forest. However, aspects of the clearcuts interacted with clearcut size to modify snow conditions. On northern aspects, snow disappeared in the clearcuts and in the forest almost simultaneously. The greatest difference in effect of block size on SWE was on the southern aspect which may have been a slope artifact. The greatest response of SWE to clearcutting was on the eastern aspect. Proc. Western Snow Conf. 39: 27-33.

20 Betts, N.DeW. 1916. Notes on forest cover and snow retention on the east slope of the Front Range in Colorado. Proc. Soc. Amer. Foresters 11: 27-32.

(Forest Cover, Elevation, Temperature/Snowmelt/ U.S. Mountains)

Examines effects of elevation on snow retention and subsequent snowmelt. Catch-basins lying above timberline were superior for the retention of snow. This superiority was not due to the absence of trees, but to their location in regard to precipitation, wind, and summer climate. The rate of discharge from melting snow differed according to the time of year that the spring snowmelt occurred.

21 Bilello, M.A., R.E. Bates, and J. Riley. 1970. Physical characteristics of the snow cover, Fort Greely, Alaska, 1966-1967. U.S.A. Cold Regions Research and Engineering Laboratory. Tech. Rep. No. 230, 33 pp.

(General, Forest Cover/Snow Depth, Snow Density, Snow Hardness/Arctic-Subarctic)

Snow density is low in forests; usually less than 0.230 g cm^{-3}. Snow and air temperatures were warmer in open than in the forest. Snow density was linearly related to the log of the geometric mean of snow hardness with a correlation coefficient of 0.76. In only the top layer, the correlation coefficient was 0.88.

22 Boyer, P.B. 1954. Heat exchange and melt of late season snow patches in heavy forest. Proc. Western Snow Conf.

22: 54-68.

(Canopy Cover, Temperature, Shade/Snowmelt/
U.S. Mountains)

Analysis of snowmelt under heavy forest during 5 days in July. A total of 85% of the melt was attributable to air temperature and humidity and 15% to short-wave radiation. These determinations were late in the season and the high temperatures may not reflect melt processes at earlier dates.

23 Buhler, A. 1886. Untersuchungen uber Schneebruchshaden. Forstw. Centbl. 8: 485-506.

(Crown Characteristics, Forest Composition/Snow Interception/Europe)

Breakage occurred in a snowstorm near Zurich when snow catch was 26 mm in hardwoods and 46 mm in conifers. This difference reflects the more vulnerable branching habits of hardwoods. Wide separation of branch whorls reduces capacity for snow storage in Scotch pines. Snow lies in interior and lower parts of bare hardwoods and on the upper whorls and ends of branches in conifers. Conifers are therefore more susceptible to top break.

Not seen - cited in Miller (1964).

24 Bunnell, F.L. 1978. Snow, trees, and ungulates. Rept. to British Columbia Fish and Wildlife Branch CARP. 72 pp.

(General, Slope, Aspect, Temperature, Elevation, Canopy Cover, Forest Composition, Wind/Snowpack, Snow Depth, Snowmelt, Snow Density, Snow Interception, Snow Accumulation/General)

A literature review of the effects of snow (as they are influenced by terrain and forests) on animal locomotion. Part I deals with factors affecting heat transfer to and from the snowpack. Part II treats the influences of topography and forest cover on snow depth and distribution. Part III deals with factors affecting snow density. The remainder of the report treats the effect of snow on ungulates and management considerations.

25 Burger, H. 1948. Einfluss des Waldes auf die Hohe der Scheedecke. Jour. Forestier Suisse 99: 225-231.

(Forest Type, Aspect, Forest Openings/Snow Depth/Europe)

Data are given for 31 years relating snow depth to forest type and aspect. The greatest depths were found on north

facing slopes and in openings between crowns.

Not seen - cited in Kittredge (1953).

26 Carpenter, L.G. 1901. Forests and snow. Colo. Agric. Exp. Sta. Bull. 55.

(Keywords to come)

Not seen.

27 Church, J.E. 1912. The conservation of snow: its dependence on forests and mountains. Scientific American Supplement 74: 145, 152-155.

(Forest Openings, Canopy Cover, Forest Composition, Crown Characteristics/Snowpack, Snowmelt/ U.S. Mountains)

An early classic which has had tremendous impact on U.S. snow studies. The greatest depth of snow occurs in openings to the lee of trees. Gathering quantitative data on this phenomena led Church to develop the Mt. Rose snow sampler in 1908. The sampler is described. Forests "anchor" the snow and protect it from erosion and sun. Interception is proportional to the density and width of the crowns and the closeness of the trees. A forest may be too dense to permit the maximum quantity of falling snow to reach the ground. Data are given illustrating this principle.

Greatest accumulations were found in fir forests containing numerous open glades, intermediate accumulations in the more uniform pine and fir forests, and the least under dense fir stands. Rates of depletion of the snowpack ("snowmelt") were greatest in open meadows, intermediate in the more open forest stands, and least in those most dense. The now famous statement is presented that the best forest for snow conservation is one which, viewed from above, would resemble a gigantic honeycomb with forest glades being proportioned so that the height of the trees would screen the sun.

28 Church, J.E. 1914. Recent studies of snow in the United States. Quart. J. Roy. Meteor. Soc. Lond. 40(169): 152-155.

(Keywords to come)

Not seen.

29 Church, J.E. 1941. The melting of snow. Proc. Central Snow Conf. 1: 21-32.

(Keywords to come)

Not seen.

30 Church, J.E. 1942. Interception of snow by tree crowns. Report of Committee on Snow, 1941-1942. Trans. Am. Geophy. Union 23: 411.

(/Snow Interception/General)

Less snow than rain is intercepted by tree crowns but it remains longer in the crown. Wind is particularly effective in shaking snow down. Insolation causes wet snow to slip off. Only in sunless weather does snow cling for long.

31 Cline, R.G., H.F. Haupt, and G.S. Campbell. 1977. Potential water yield response following clearcut harvesting on north and south slopes in northern Idaho. USDA For. Serv. Res. Pap. INT-191, 16 pp.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

Measurement stations were set up on north and south slopes in both virgin forest and clearcuts. The SWE's were 14.0 and 32.3 inches for north-facing forests and clearcuts respectively and 18.3 and 25.9 inches for south-facing forests and clearcuts respectively. During the winter, snowmelt was least on the north-facing forested area and greatest on the north clearcut. The greatest gain in snowmelt was achieved by logging north slopes. The south clearcut was located near a ridgetop and may have lost much snow through wind scouring and cornice formation.

32 Clyde, G.D. 1931. Snow-melting characteristics. Utah Agric. Exp. Stat. Tech. Bull. 231: 1-47.

(Keywords to come)

Not seen.

33 Colman, E.A. 1953. Vegetation and watershed management. The Ronald Press Co., New York. 412 pp.

(General//General)

Evaluated by present standards this book contributes relatively little to forestry-snow inter-relationships. Its scope is much broader and its approach tends more to

description than to synthesis. It might prove a helpful repository of older references for those primarily interested in water yield. It does provide general statements on "snow accumulation and dissipation" (p.74-77) and "management of the snowpack" (p.325-340). The latter discussion includes a number of references to forested ecosystems, all but two (not retrievable) of which are included within this bibliography.

34 Connaughton, C.A. 1935. The accumulation and rate of melting of snow as influenced by vegetation. J. Forestry 33: 564-569.

(Forest Openings, Canopy Cover, Crown Characteristics/ Snow Depth, Snowpack, Snowmelt/U.S. Mountains)

Maximum snow depth and SWE were measured on five plots; open, sagebrush, reproduction (trees 20 to 25' on an area logged 8 years previously), virgin timber with no advance reproduction and virgin timber with advance reproduction. Area was ponderosa pine land in Idaho. On average, the SWE of the open and sagebrush plots were identical. The reproduction plot had 5.4% less snow, while the two virgin plots had 24.5% (lacking advanced regeneration) and 29.8% (with advanced regeneration) lesser maximum SWE's than the open plots. Small openings in the trees were nearly as effective (95%) in accumulating snow as large open areas. The high spreading crowns of mature trees intercepted more snow than an equal crown area of smaller trees (less than 80 years old).

Melt rates were slower in the vegetated plots. The open and sagebrush plots became totally clear of snow within one day of the first bare ground appearing; patches of bare ground appeared in the forest almost as soon as melt began. Most of the snow remaining in the forest (after melting was complete in the open) was concentrated on the north sides of trees and beneath dense shade. Amounts of snow remaining after melt was complete in the open (as a % of snow present at beginning of melt) were: 6% in mature timber without advance regeneration; 14% in the regeneration plot; 20% in mature timber with advance regeneration. Young growth exercised the greatest influence in retarding snowmelting (but had less influence on snow interception).

35 Court, A. 1957. Wind direction during snowfall at Central Sierra Nevada Snow Laboratory. Proc. Western Snow Conf. 25: 39-43.

(Wind/Snow Deposition/U.S. Mountains)

In the Sierra Nevada only 2% of the precipitation (snow) fell during calm periods.

36 Court, A. 1963. Snow cover relations in the Kings River Basin, California. J. Geophys. Res. 68(16): 4751-4761.

(Elevation/Snowpack, Snowmelt/U.S. Mountains)

The aerial extent of snow cover was calculated through several springs. The snow-covered area decreased at the same rate each year regardless of whether the snowpack was light or heavy; the snowline rose 70 ft day^{-1}. Snowcourses run through level meadows overestimated total Snowpack of watersheds by 7-8 inches SWE.

37 Cramer, H.H. 1960. Hubschrauber gegen Schneebruchschäden Allgem. Forstzeits. 15(20): 293,296.

(Wind/Snow Interception/Europe)

The wind caused by a helicopter cleared snow only from the top 2-3 m of the canopy and left snow undisturbed on lower branches. Cited as evidence that snow masses in trees resist mechanical removal unless strong winds directly follow the snowstorm.

Not seen - cited in Miller 1962.

38 Delfs, J. 1955. Die Niederschlagszuruckhaltung in Walde (Interception). Mitt. Arbeitskresses "Wald und Wasser" (Koblenz), No. 2. 54 pp.

(Canopy Cover, Crown Characteristics/Snow Deposition, Snow Interception/Europe)

When snow approaches the canopy at low angle, the effective surface of the canopy is increased resulting in increased snow storage. Interception is greatest in spruce varieties that have side branches rising sharply upwards.

Not seen - cited in Miller (1964).

39 Delfs, J. 1955. Die Niederschlagszuruckhaltung in den Bestanden-Interception. Aus dem Walde (Hannover) 3: 76-107.

Not seen.

40 DeWalle, D.R., H.A. Parrott, and J.G. Peters. 1977. Effect of clearcutting deciduous forest on radiation exchange and snowmelt in Pennsylvania. Proc. Eastern Snow Conf. 34: 105-117.

(Forest Openings/Snowmelt/Eastern U.S.)

Net radiation in a clearcut averaged 16% more than above a deciduous forest canopy and 86% more than beneath it. Snowmelt was more than twice as rapid in the clearcut. Nearly all of the difference in melt rate was due to the difference in net radiation.

41 Dietrich, T.L., and J.R. Meiman. 1974. Hydrologic effects of patch cutting of lodgepole pine. Colo. St. Univ. Hydrol. Pap. 66, 31 pp.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

Prefaced by a good review of research done on the effect of vegetation manipulation on snow cover. Snow was measured for three years in lodgepole pine forests, then openings 5 TH in diameter were cut. Cutting seemed to produce little change in average SWE. There were obvious drift areas in the cuts, however. Decreases in SWE along northern borders of the cuts occurred due to solar radiation. Melt was slowest in the drift area on the west side of the cuts.

42 Dils, R.E., and J.L. Arend. 1956. Snow accumulation under red pine of different stand densities in lower Michigan. USDA For. Serv. Lake States For. Exp. Stat. Tech. Note 460. 2 pp.

(Forest Density/Snow Depth/Eastern U.S.)

A red pine plantation of 190 ft^2 $acre^{-1}$ was thinned to 6 different stocking levels from 60-160 ft^2 $acre^{-1}$. Snow depth decreased with increasing stocking rate. A graph representing this relationship is presented.

43 Doty, D.D., and R.S. Johnson. 1969. Comparison of gravimetric measurements and mass transfer computations of snow evaporation beneath selected vegetation canopies. Proc. Western Snow Conf. 37: 57-62.

(Canopy Cover/Snowmelt/U.S. Mountains)

A study of snow evaporation in the open, under aspen and under conifer. Evaporation was greatest in the open and least under the conifer stand. Evaporation amounted to no more than 5% of SWE in the open. Condensation would negate much of this loss. Evaporation is concluded to be a negligible snow loss component.

44 Dunford, E.G., and C.H. Niederhof. 1944. Influence of aspen, young lodgepole pine and open grassland types upon factors affecting water yield. J. Forestry 42: 673-677.

(Forest Openings, Forest Composition/Snowpack, Snowmelt/ U.S. Mountains)

Snow measurements were made in the spring within 3 cover types; aspen, lodgepole pine and grass. The most snow accumulated in the aspen and the least in the lodgepole stand. Snow melted most rapidly in the open and at the same rate in the aspen and lodgepole stands. Both types were bare one week following the open field.

45 Eastman, D.S. 1978. Habitat selection and use in winter by moose in sub-boreal forests of north-central British Columbia, and relationships to forestry. Ph.D. thesis, Univ. of British Columbia, Vancouver, 554 pp.

(Forest Composition, Forest Density, Canopy Cover, Forest Openings/Snow Depth, Snow Hardness/Boreal Canada)

Snow stations were run for two winters with measurements made of depth, density and surface hardness; the latter with a spring-loaded penetrometer similar to the NRC gauges. Hardness measurements at each station were highly variable. Snow depths at open or deciduous sites, partially cutover locations and coniferous forests exhibited a ratio of 100:75:50. The uniformity of snow cover was greatest in the open, intermediate in the forest and least in the partial cutovers. There was no habitat effect on snow density. Snow duration was dependent upon site specific accumulations and melt rates. Approximately 36% of the snow was intercepted by the forest. Coniferous forest does not seem to intercept snow effectively until the canopy cover reaches 44%. Predicting interception requires stratification of forest types, climatic zones and stand paramaters. Crown closure was weakly correlated to interception ($r^2 = 0.15$). Golding and Harlan's (1972) method using the Bitterlich point-sampling technique gave no significant relationship.

46 Eidmann, F.E. 1954. Zum Wasserhaushalt von Fichten - und Buchenbestanden (Vorlaufiger Bericht). Mitt. Arbeitskreises "Wald und Wasser" (Koblenz). 1: 45-50.

(Canopy Cover, Slope/Snow Interception/Europe)

Spruce intercepts more snow on slopes perhaps because the crowns are more densely closed.

Not seen - cited in Miller (1964).

47 Eschner, A.R., and D.R. Satterlund. 1963. Snow deposition and melt under different vegetative covers in central New York. USDA For. Serv. Res. Note NE-13. 6 pp.

(Canopy Cover/Snow Accumulation, Snowmelt/Eastern U.S.)

Snowcourses were run through seven cover types. Average maximum SWE and total accumulations were inversely correlated with canopy cover. Less snow accumulated on the open areas because it was blown away. Average snow density increased about 38% just prior to melt. The date at which half of the snow had melted was earliest for the open and brushy areas (CC=2.8%), a week later in the northern hardwoods (CC = 7.6%) and thinned spruce (CC = 94%), 4 or 5 days later in red pine stands (CC = 85 and 93%) and 5 days later still in the dense spruce (CC = 96%). (CC = canopy cover).

48 Farnes, P.E. 1971. Mountain precipitation and hydrology from snow surveys. Proc. Western Snow Conf. 39: 44-49.

(Canopy Cover/Snowpack/U.S. Mountains)

Snow accumulation is related to canopy cover as measured by the photocanopymeter within a 30° cone. Figure 2 shows linear relationship between snow accumulation and canopy cover ($y = 0.5x + 100.00$ where y = % SWE under the canopy relative to the open and x = % canopy cover). The "snow course factor" is the multiplier used to estimate SWE if all canopy were removed. This conversion was used to predict run-offs.

49 Farnes, P.E. 1973. Development and use of mountain precipitation map. Pages 64-75 in: The role of snow and ice in hydrology. Proc. Banff Symp., Sept. 1972. UNESCO/WMO/IAHS.

(Canopy Cover/Snowpack/U.S. Mountains)

Similar to Farnes (1971). For snow courses located in timbered areas, amount of snow in open areas is determined by adjusting snow course data for canopy cover. This adjustment is made on the basis of canopy data from the photocanopymeter. A curve is given relating the ratio of snow in the open to snow in the trees (the "snow course factor") to canopy cover.

50 Federer, C.A., and R.E. Leonard. 1971. Snowmelt in hardwood forests. Proc. East. Snow Conf. 28: 95-109.

(Forest Composition/Snowmelt/Eastern U.S.)

Snowmelt differences among forest covers result from differences in energy transfers by solar and longwave radiation, convection, and the condensation-evaporation balance. Absorption of solar radiation can be estimated with a canopy model. During the day, longwave radiation

influx is greater in hardwood forests than in the open. Air temperature and humidity are equal in hardwood stands and the open whereas windspeeds in hardwoods are 1/2 those of the open.

51 Ffolliott, P.F., E.A. Hansen, and A.D. Zander. 1965. Snow in natural openings and adjacent ponderosa pine stands on the Beaver Creek watersheds. USDA For. Serv. Res. Note RM-52, 8 pp.

(Forest Type, Forest Openings/Snow Depth, Snow Interception, Snowmelt/U.S. Mountains)

Snow accumulation and melt were studied in natural openings downwind of ponderosa pine forest of various ages. Accumulation in the openings was unrelated to upwind stand type. Most snow was held in the "zone of retention" extending from the edge to 1.5 to 2 TH downwind. In general, snow farthest from the canopy melted fastest. Uneven-aged stands accumulated more snow than even-aged ones and showed slower rates of snowmelt. Snow gauges exhibited no more deposition within the first 2 TH of the opening and there appeared to be no drifting from the centre of the cut. Eddy effects may reduce catches by standard gauges.

52 Ffolliott, P.F., and J.R. Thompson. 1976. Snow damage in Arizona Ponderosa pine stands. USDA For. Serv. Res. Note RM-322. 2 pp.

(Forest Density/Snow Interception/U.S. Mountains)

Most of the snow damage in a ponderosa pine stand consisted of stem bending of trees of 2 inch d.b.h. Dense sapling stands suffered more damage than thinned ones because the dense, meshlike canopy structure of the dense stands collected more snow.

53 Ffolliott, P.F., and D.B. Thorud. 1969. Snowpack density, water content and runoff on a small Arizona watershed. Proc. Western Snow Conf. 37: 12-18.

(Canopy Cover, Elevation/Snow Density/U.S. Mountains)

A study of snowpack "ripening" in Arizona. One aspect deals with the effects of timber stocking, elevation, and insolation. Higher snow densities were observed under sparsely stocked relative to dense stands and at higher elevations. There was no correlation between density and insolation. Microrelief is less important in this zone. Snow in the forest is usually less dense, more uniform and deeper. Wind is the major factor influenced.

54 Ffolliott, P.F., and D.B. Thorud. 1972. Use of forest attributes in snowpack inventory - prediction equations. J. Soil and Water Conserv. 27: 109-111.

(Forest Density, Aspect, Slope/Snowpack, Snowmelt/ U.S. Mountains)

Measurements not normally included in forest inventory are needed for snowpack prediction. Separation of variables is particularly difficult. This study empirically documents the relative significance of forest density and potential direct-beam solar radiation. Five forest density parameters were utilized and the data of Frank and Lee (1966 USDA Res. Pap. RM-18) were used for the radiation factor. Simple regressions of several forest attributes and radiation on snowpack were significant (r's of 0.68-0.82).

55 Fiebiger, G. 1976. The influence of relief and vegetation on snow deposition in the Alps with special regard to the effects on skiing areas. Proc. Eastern Snow Conf. 33: 156-162.

(Forest Openings/Snow Depth, Snow Density/Europe)

Because trees act as a wind break, snow which would ordinarily be blown clear is deposited on forested ridge-tops. This relationship is illustrated graphically. The zone up to timber-line is called the "forest tension zone".

56 Fitzharris, B.B. 1975. Snow accumulation and deposition on a wet coast mid-latitude mountain. Ph.D. thesis, Univ. of British Columbia, Vancouver, B.C. 367 pp.

(Forest Openings, Elevation, Canopy Cover/Snow Deposition, Snow Interception. Snowpack/Canadian West Coast)

Development of a predictive model for snow accumulation and deposition on Mt. Seymour, B.C. Data are presented from 12 stations ranging in elevation from 120-1260m. At each station, readings were taken in open areas (> 3 TH in diameter), clearings (1/4 - 3 TH in diameter), the canopy edge, beneath the canopy, and < 1 in from tree trunks. Snow accumulation in clearings was not significantly different from accumulation in open areas at any elevation but the snowpack remained longer. There was no consistently different accumulation of snow at forest edges or under the canopy as compared to clearings. Snow hollows around trees were usually significantly different in depth and occurred higher in elevation as the season progressed. Snowpack density did not vary consistently with altitude nor with forest cover although densities were high near trees due to melt drip. Stepwise

regression was used to predict snow in the forest using an equation incorporating squared terms for snowfall and elevation to incorporate logarithmic interception curves described by Watanabe and Ozeki (1964) and Satterlund and Haupt (1967). Correlation coefficients between observations and predictions for clearings, canopy edge, beneath canopy and near tree trunks were 0.95, 0.83, 0.78, and 0.75 respectively. There was a noticeable elevation-cover interaction. At high elevation, wind scour removes snow from forest edges. At low elevation, less snow is deposited in clearings relative to open areas. Above 870 m, there is a substantial excess of snow in clearings. Interception of snow by the forest canopy is most marked in the wet snow zone because the particles are heavier, fall more vertically and therefore are more readily intercepted. During heavy snowfalls, intercepted snow falls from the branches generating a curvilinear relationship between snow deposition in open and under canopy. At high elevations, snow is blown from open areas into the trees. Accordingly, data were reanalyzed after grouping into three zones; the drift snow zone, the wet snow zone, and the snow zone all defined by freezing level. The predictive equations and general model were felt to be area specific.

57 Formosov, A.N. 1946. Snow cover as an integral factor of the environment and its importance in the ecology of mammals and birds. Translated and published by the Boreal Institute, Univ. of Alberta, Edmonton, Alberta, Canada. Occasional Paper No. 1. 141 pp.

(Forest Type, Forest Density/Snow Depth, Snowmelt, Snow Interception, Snow Density/USSR)

Contains a chapter dealing with snow in forested regions which provides Siberian terminology for snow types, describes lesser snow accumulations in the forest, forest effects on snow density and on melt rate. Includes a review of the early Soviet literature on forest-snow relations.

58 Fowler, W.B., and H.W. Berndt. 1971. Efficiency of foliage in horizontal interception. Proc. Western Snow Conf. 39: 27-33.

(Crown Characteristics, Forest Composition/Snow Interception/U.S. West Coast)

A description of how foliar characteristics affect rime and hoarfrost collection in Washington. Cylinders of various sizes, branches of alpine fir and lodgepole pine, and a 7 ft lodgepole pine were continuously weighed. The surface area of needles on the tree was 223,000 cm^2. Within the first 12 hours, there was no species effect on

rime collection. Many aspects of the process remain to be investigated.

59 Garstka, W.U., L.D. Love, B.C. Goodell, and F.A. Bertle. 1958. Factors affecting snowmelt and streamflow. USDI, Bureau of Reclamation and USDA For. Serv., Rocky Mountain For. and Range Exp. Stat. 189 pp.

(Slope, Aspect, Temperature, Canopy Cover/Snowpack, Snowmelt/U.S. Mountains)

A report of snow research from 1946-1953 at the Fraser Experimental Forest, Colorado. Largely concerned with snowmelt runoff and streamflow. Section 2 reviews the literature on forest effects on snowmelt and snow accumulation. Section 6 deals with forest and aspect effects on snow disappearance.

60 Gary, H.L. 1974. Snow accumulation and snowmelt as influenced by a small clearing in a lodgepole pine forest. Water Resources Research 10: 348-353.

(Forest Openings/Snow Deposition, Snowmelt/ U.S. Mountains)

A clearing 1 TH wide and 5 long was cut in a thinned lodgepole pine stand. There was increased accumulation in the clearing and reduced accumulation downwind. These increments and deficits cancel out which is in accord with the hypothesis of Hoover and Leaf (1967). The relative depths were maintained through the melt season; snow disappeared first on the leeward side and north side of the clearing. Melt rates were about twice those in the forest. It was concluded that openings affect snow distibution but not the total amount of snow.

61 Gary, H.L. 1974. Snow accumulation and melt along borders of a stripcut in New Mexico. USDA For. Serv. Res. Note RM-279. 8 pp.

(Shade, Forest Openings/Snowmelt, Snow Deposition/ U.S. Mountains)

Report of a 2-year study of snow accumulation and melt along the sunny and shady borders of an east-west oriented powerline cut through an Engelmann spruce stand. There was little difference between sunny and shady areas in snow catch. Water loss by evaporation was twice as great on the sunny areas but was probably an insignificant influence. Distinct differences occurred in rates of snowmelt. When snowmelt was complete along the sunny border, 86-95% of the maximal snowpack remained along the shady border. Complete melts along the shady border and

in the forest were 5-6 weeks later than along the sunny border. Daily melt rates were 30-40% greater along the shady borders than in the forest but the reduced snowpack in the forest resulted in near identical dates of complete melt. Clearings 5-8 TH in diameter will accumulate maximal amounts of snow largely collected from the surrounding forest. Clearings as small as 1 TH will accelerate snowmelt with respect to the forest.

62 Gary, H.L. 1975. Airflow patterns and snow accumulation in a forest clearing. Proc. Western Snow Conf. 43: 106-113.

(Forest Openings, Wind/Snow Deposition/U.S. Mountains)

An investigation of the question whether relatively large snow accumulation in clearings is due to theft from the surrounding forest or from interception and evaporation in the canopy. Windspeed in the forest was least where canopy biomass was greatest due to the larger number of frictional surfaces. Since this was in the mid-canopy region, windspeeds above and below the canopy were independent. Snow distribution under the canopy was more influenced by sub-canopy flow than by penetration of winds through the canopy. Clearing a strip one TH wide resulted in large snow buildups to the windward and depletion to the leeward. In total more snow was found in the clearing and less in the forest. Excess and deficit amounts were about equal. Airflow consisted of two regions; one a closed eddy extending from the middle of the clearing to 4 m downwind of the lee clearing edge; the other an upward flow on the windward side of the clearing. Maximum deposition was near the junction of the two airflows. Maximum depletion was in a slow air movement zone indicating that windscouring was not the cause of depletion.

63 Gary, H.L. 1979. Duration of snow accumulation increases after harvesting in lodgepole pine in Wyoming and Colorado. USDA For. Serv. Res. Note RM-366. 7 pp.

(Forest Openings, Crown Characteristics/Snowpack/ U.S. Mountains)

A three-part study done in Wyoming lodgepole-pine forest. In Part I, east-to-west transects were run across a series of several 125-150 m wide north-south running strips that had been cut 20 years earlier. The strip cuts were well stocked with trees 3-6 m in height. Point-to-point variation in snow measurement was largely due to the variable pattern of stocking. Low snow accumulation occurred on the windward forest. On north slopes, strips held 15-30% more snow, on south slopes corresponding values were 41-60%. Part II involved cutting a section of

the bole from trees in 2 TH wide areas and then bolting the tops back onto the stump. Paired clear-cut areas the same size were also cut. The clearings held 30% more SWE with greater accumulations to the windward. The increment seems to have been "stolen" from the downwind forest. Where TH was reduced by 1/2, the lower branches touched the ground causing sliding snow to accumulate between trees and therefore producing a very uneven snow accumulation. Snow catch increased 14% compared to the undisturbed forest. In the plot where TH were reduced by 25%, 13% more snow accumulated. This increment appears due to differential evaporation and/or sublimation due to greater protection of the snow surface by lowered canopy levels. Part III consisted of the analysis of snow course data on an area clearcut 38 years earlier. Increased snow accumulation was still apparent.

64 Gary, H.L., and G.B. Coltharp. 1967. Snow accumulation and disappearance by aspect and vegetation type in the Santa Fe Basin, New Mexico. USDA For. Serv. Res. Note RM-93. 11 pp.

(Elevation, Aspect, Canopy Cover/Snowpack, Snowmelt/ U.S. Mountains)

Paired north and south facing study plots were established in four vegetation types; Douglas-fir, aspen, spruce-fir and grass. Stand conditions were expressed in stems acre^{-1}, basal area acre^{-1}, and volume acre^{-1}. SWE was determined weekly. Douglas-fir and aspen plots were at 9,900 ft elevation whereas the spruce-fir and grass plots were at 11,150 ft. Maximum SWE was found on the two high elevation grass plots followed by the high elevation spruce-fir plots. At lower elevations, the north-facing aspen and Douglas-fir plots held more water than the south facing plots. At low elevation, the south-facing plots exhibited snow disappearance 4-5 weeks earlier than on the north. At high elevation, there was no aspect differential in snow disappearance; snow disappeared in the grass type about the same time as on north slopes at lower elevations. Snow disappearance under the spruce-fir type took 4-5 weeks longer.

65 Gay, L.W. 1958. The influence of vegetation upon the accumulation and persistence of snow in the Australian Alps. Unpubl. thesis, Australian Forestry School, Canberra.

(Keywords to come)

Not seen.

66 Geidel, R.W. 1944. Discussion. (Hydrology of small watersheds under winter conditions of snow-cover and frozen soil). Amer. Geophys. Union Trans. 25: 871-874.

(General/Snowpack/Eastern U.S.)

Little useful information.

67 Geiger, R. 1961. The climate near the ground. Harvard University Press, Cambridge, Mass. 611 pp.

(Elevation, Slope, Aspect, Temperature, Shade/Snow Interception/General)

The classic text of forest micrometeorology. Pages 337-338 discuss snow interception somewhat superficially. More snow reaches the ground than does rain.

68 Gill, J.D. 1958. Shelter requirements of deer. Job Compl. Rept., P-R Proj. W-37-R-7, Job 4-D. 4pp. Maine Dept. of Inland Fisheries and Game. 2 pp.

(Canopy Cover/Snow Depth, Snow Interception/Eastern U.S.)

The amount of snow interception by conifers and hardwoods varies considerably but snow depths under conifer stands of 90% crown closure are invariably less than under nearby hardwoods.

Not seen - cited in Boukhout (1972. M.Sc. thesis, Univ. of Calgary).

69 Gold, L.W. 1956. The strength of snow in compression. J. Glaciol. 2(20): 719-725.

(General, Temperature/Snow Density, Snow Hardness/General)

A discussion of the strength of snow (as measured by a snow hardness guage - NRC type) and its relationships with density, temperature, and grain size of the snow. Data were collected from 13 different stations across Canada. The strength of snow was found to be highly variable primarily due to the variable bonding between snow grains and the subsequently variable density of snow.

70 Gold, L.W. 1958. Changes in a shallow snow cover subject to temperature change. J. Glaciol. 3(23): 218-222.

(General, Temperature/Snowpack, Snow Depth, Snow Density/Boreal Canada)

Observations of a snowpack as it was changed by a

temperate climate are reported and discussed. Specific observations include height of the snow layer, density of snow in each layer, grain size distribution in each layer, and grain type in each layer.

71 Golding, D.L. 1968. Regulation of water yield and quality in British Columbia through forest management. Ph.D. thesis, Univ. of B.C. Vancouver, B.C. 406 pp.

(General/Snowpack, Snowmelt, Snow Interception/Canadian West Coast, Canadian Mountains)

A largely policy-oriented document dealing with the effect of logging on streamflow in B.C. Pages 26-39 present a useful review of snow interception, accumulation, evaporation, and melting studies.

72 Golding, D.L. 1970. Research results from Marmot Creek experimental watershed, Alberta, Canada. Proc. of a Symp. on the results of research on representative and experimental basins, Wellington New Zealand. Intl. Assn. Scientific Hydrology Publ. 96: 397-403.

(Forest Density/Snowpack/Canadian Mountains)

Five 10-point snow courses were run through uniform topographic and forest conditions. Stand density was measured using the Bitterlich point-sampling technique with three angle sizes. The relation between SWE and forest density was linear but intercept and slope were date dependent. The final model for date of maximum Snowpack gave a multiple correlation coefficient of 0.91. A review of other work at Marmot Basin is included.

73 Golding, D.L. 1974. The correlation of snowpack with topography and snowmelt runoff on Marmot Creek Basin, Alberta. Atmosphere 12: 31-38.

(Forest Density, Slope, Aspect, Elevation/Snowpack/ Canadian Mountains)

A multiple regression model utilizing slope, aspect, elevation, forest density (Bitterlich point-sampling), elevation x slope and the square of forest density accounted for only 36% of the variability in SWE measurements in Alberta. Adding a factor accounting for topographic position improved the model so that it accounted for 48% of the variability. In simple regression, using 3 years of data, each 100 m gain in elevation increased SWE by .07 - .15 cm for each cm of mean SWE. SWE decreased .084 - 1.07 cm per 10% gain in slope per cm of mean SWE. An increase in the tree count of one decreased the SWE by .15 - .43 cm but no

correlation was evident with annual snowpack.

74 Golding, D.L. 1977. Watershed treatment to alter snow accumulation and melt rates. Pp. 237-255 in: Alberta watershed research program symp. Proc. 31 August, September.

(Forest Openings, Aspect, Forest Type/Snowpack, Snowmelt, Snow Depth/Canadian Mountains)

A study of snow accumulation and ablation in forest openings 1/4 to 6 TH in diameter. Snow accumulation was least in the forested control, increasing gradually to a maximum in openings of 2 TH and then dropping off slowly to openings of 6 TH. SWE was 45% greater in the 2 TH opening than in the forested control. Ablation followed the same trend, but varied in degree with inter-annual differences in weather during melt season. Results of the study were applied at three locations in Alberta and found to be in agreement with the predicted trends for snow accumulation and ablation.

75 Golding, D.L., and R.L. Harlan. 1972. Estimating snow-water equivalent from point-density measurements of forest stands. Ecology 53: 724-725.

(Forest Density/Snowpack/Canadian Mountains)

A study to determine if the influence of adjacent trees on point measurements of SWE can be determined by the Bitterlich point-sampling method. This method tallies all trees around a point which subtend an angle of certain sizes. Regression of SWE on elevation gave correlation coefficients of 0.94-0.99. SWE was best correlated with point densities determined with a prism wedge of 147.34 minutes. SWE decreases as point density increases. Whereas the best prism gave correlation coefficients of -0.30 to -0.51, a regression using 3 prism angles gave correlations of -0.62.

76 Golding, D.L., and R.H. Swanson. 1976. Runoff patterns resulting from snow accumulation and ablation as influenced by mass and energy relationships in small forest openings. Marmot Creek Exp. Watershed and James River Snow Study Area, Alberta. Study Prog. Rpt. NOR-13-103.

(Forest Openings/Snowpack, Snowmelt/Canadian Mountains)

A progress report subsequently published as Golding and Swanson (1978). Openings were cut in lodgepole pine with diameters 1/4, 1/2, 3/4, 1, 2, 3, 4, 5, and 6 TH. SWE's are graphed vs diameter of the openings and show maximal

accumulation during early April in openings 3 TH in diameter, and maximal accumulation in late April, after melt was well underway, in openings 1 TH in diameter.

77 Golding, D.L., and R.H. Swanson. 1978. Snow accumulation and melt in small forest openings in Alberta. Can. J. For. Res. 8: 380-388.

(Forest Openings/Snowpack, Snowmelt/Canadian Mountains)

A study of snow accumulation and ablation in forest openings 1/4 to 6 TH in diameter. The greatest snow accumulation occurred in 2-3 TH openings. Below 3/4 TH accumulation dropped off rapidly. Ablation rates were least in 1 TH openings with maximum rates in 5-6 TH openings. It is not clear why ablation rates were so rapid in small openings and the uncut forest. Close packing of 1 TH openings resulted in accumulation and loss rates similar to more widely spaced openings of the same size.

78 Goodell, B.C. 1952. Watershed management aspects of thinned young lodgepole pine stands. J. Forestry 50: 374-378.

(Forest Density/Snowpack, Snowmelt/U.S. Mountains)

A study of the effect of thinning lodgepole stands on snow accumulation and melt as well as the amount of rain reaching the forest floor and the extent of soil moisture losses. Six blocks of thick, second-growth lodgepole pine were divided into 3 blocks each. One was left unthinned, one was thinned by a "single tree" method and the last by a "crop-tree" method which left small openings. The single tree method increased SWE by 2.31 inches and the crop-tree method increased it by 1.69 inches. The average increase was about 20%. Snowmelts in the thinned stands were increased by 2.01-2.35 inches SWE in three weeks of major melt.

79 Goodell, B.C. 1958. A preliminary report on the first year's effects on timber harvesting on water yield from a Colorado watershed. USDA For. Serv. Paper RM-36.

(Forest Openings/Snowpack/U.S. Mountains)

A preliminary report summarizing 12 years of streamflow records prior to timber harvesting and one year after completion of timber harvesting. The pre-harvest data for two adjacent watersheds enabled the calculation of regression equations for stream discharge. These equations were then used to analyze the effect of the harvest treatment on water yield. The spring flood peak

was increased the first year after cutting and decreased in comparison with the unharvested control in the second year. Extrapolating the results over the long-term is cautioned against. Goodell (1959) presents a more detailed treatment.

80 Goodell, B.C. 1959. Management of forest stands in western United States to influence the flow of snow-fed streams. Intl. Assn. Scient. Hydrology Pub. 48: 49-58.

(Forest Openings, Forest Density/Snow Interception, Snowmelt, Snow Deposition/U.S. Mountains)

Coniferous forests are highly absorptive of solar radiation, 5% is re-radiated, 10% utilized by the tree, and the rest goes to warming the tree. As little as 5% may penetrate to the forest floor. Convective heat raises the air temperature of the general area including openings which also receive direct solar radiation. Snow in openings may receive 65% more heat than forest-shaded snow. Therefore snowmelts only 70-80% as fast under the canopy. Research on melt rates in forest openings is reviewed. Trees also intercept snow which is lost by evaporation. The energetics of sublimation and evaporation are discussed. There are few data on evaporation and sublimation rates. Data are presented for interception of snow in Colorado. There is a near linear and inverse relationship between stand density ($m^2 ha^{-1}$) and snow reaching the ground. Stands with 168 m^2 ha^{-1} received 29% less snow than cutover areas. Data from Goodell (1952) are reiterated showing the effects of thinning on snow interception. Love's (1953) data are presented showing that the pattern of forest cutting has little or no effect on interception.

81 Goodell, B.C. 1963. A reappraisal of precipitation interception by plants and attendent water loss. J. Soil and Water Conserv. 18: 231-234.

(General/Snow Interception/General)

A theoretical investigation of the claim that precipitation interception, and attendent vaporization, cause a compensating reduction in transpiration yielding little or no net loss to the atmosphere. The technique of comparing snow depths in the forest and in openings is subject to criticisms that the differences are due to differential distribution rather than loss. There are theoretical reasons to suggest that there is insufficient energy available to vaporize large quantities of snow or water. The transpiration hypothesis is questioned on the basis of several theoretical considerations.

82 Government of Japan. 1952. Study of the fallen snow on the forest trees (snow crown). Bull. Government For. Exp. Stat. Japan (Meguro) 54: 115-164.

(Keywords to come)

Not seen.

83 Griffen, A.A. 1918. Influence of forests upon the melting of snow in the Cascade Range. Monthly Weather Review 46: 324-327.

(Forest Openings, Forest Density, Canopy Cover, Aspects, Elevation/Snowpack, Snowmelt/U.S. Mountains)

A study from 3 areas in Washington and Oregon to determine how much longer forested sites retain snow relative to open areas (east side of the Cascades north and south of Columbia River). The mean figure for forests of Douglas-fir, mountain hemlock and lodge-pole pine was 17 days with some forested stations keeping their snow for 42 days after melt was complete in the open. When snow had disappeared from the open areas, 7 inches of water (30% maximum snow water storage) still remained on the ground in the forest, and the bulk was held in small openings in the denser stands. Cover density was classified into 4 groups. Denser forests maintained snow longer. Snow accumulation was less in denser forests. There was no evidence of an aspect, elevation or slope effect. Forest litter can slow melt rates by providing insulation. In the open, litter accelerates melt.

Bullard (1950) reported that part of the study was continued in the mid-1930's at Wind River. Results showed that "snow on open cut-over land disappeared a week before that in partially cut stands, and two weeks before snow disappeared in the untouched, old-growth stands. On open lands, 70% of the original snowpack melted in one week; under timber cover snowmelt was evenly distributed over a four-week period (Bullard 1950, p.4; original not seen cited from Colman 1953).

84 Hale, C.E. 1950. Some observations on soil freezing in forest and range lands of the Pacific Northwest. USDA For. Serv. Pacific Northwest For. and Range Exp. Stat. Res. Note 66. 17 pp.

(Canopy Cover/Snowpack/U.S. West Coast)

Eight plots were established in Douglas-fir stands which had undergone different cutting intensities. Crown-cover was 0, 20, 40, and 90%. Snow depth and density varied inversely with stand density. Rates of snowmelt varied directly with stand density. Figures and tables

illustrate these conclusions.

85 Hansen, E.A., and P.F. Ffolliott. 1968. Observations of snow accumulation and melt in demonstration cutting of Ponderosa pine in central Arizona. USDA For. Serv. Res. Note RM-111. 12 pp.

(Slope, Forest Openings/Snow Accumulation, Snowmelt/ U.S. Mountains)

To enhance snow accumulation and retard snomelt, forests were clearcut on north aspects, stripcut on intermediate aspects and cut in narrow strips on south aspects. Clearcutting the north slope resulted in 2.5-4 inches more SWE than in the adjacent uncut timber (160 ft^2 acre). Slash removal had no noticeable effect on SWE. Snow melted 3-8 days earlier than in the adjacent uncut forest. A 3/4 TH strip cut on western slope increased snow accumulation by 0.75 in over surrounding forest (190 ft^2 $acre^{-1}$). Snowmelt was most rapid on the sunny side of the cut. Snow disappeared in the forest 10 days before snow in the stripcut. Although melt rates were higher in the strip cut, snow remained longer than in the forest. More snow accumulated in the forest to the windward of the cut and less accumulated to the leeward. Essentially the same pattern was observed in stripcuts 1.5 TH wide on east slopes. Stripcuts of 0.5 and 1 TH on south facing slopes had little consistent effect on snow accumulation or melt.

86 Harestad, A.S., and F.L. Bunnell. 1979. Snow and its relationship to deer and elk in coastal forests. Report to B.C. Council of Forest Ind. 53pp

(Canopy Cover/Snow Depth, Snow Density/General)

A synthesis paper assessing the effects of snow on deer energetics and of forestry practices on snow. Using published data, a regression is developed relating SWE in the open to the slope of a snow depth-canopy cover relation. A smaller proportion of snow is captured by the canopy in areas of heavier snowfall. The density of new snow beneath tree crowns may be much denser than snow in openings due to compaction of snow masses sliding from branches. This difference is lost as the pack matures.

87 Harestad, A.S., and F.L. Bunnell. 1981. Snow: canopy cover relationships in coniferous forests. Can. J. For. Res. (in press).

(Canopy Cover/Snow Interception/General)

A review paper evaluating the relationship between canopy cover and reductions in snowpack. Literature review

reveals substantial differences between areas in this relationship. Canopy cover exerts less of an influence on snowpack reduction in high snowfall areas. A regression equation is developed relating percentage of snow interception to total snow accumulation in the open.

88 Harlan, R.L. 1969. Soil-water freezing, snow accumulation and ablation in Marmot Creek experimental watershed, Alberta, Canada. Proc. Western Snow Conf. 37: 29-33.

(Forest Density/Snowpack, Snowmelt/U.S. Mountains)

Presents SWE's under immature lodgepole pine, cutover spruce-fir and mature spruce fir. There was no difference in mid-March snowpack. However, differential ablation thereafter caused wide discrepancies between snowpacks. The snow in the immature lodgepole pine depleted rapidly. Forest characteristics are listed by species, basal area acre^{-1}, mean dbh, and stems acre^{-1}.

89 Harrington, M.W. 1893. Review of forest meteorological observations: A study preliminary to the discussion of the relation of forests to climate. USDA For. Serv., For. Div. Bull. 7: 23-122.

(Keywords to come)

Not seen.

90 Hart, G. 1963. Snow and frost conditions in New Hampshire under hardwoods and pines and in the open. J. Forestry 61: 287-289.

(Canopy Cover/Snowpack, Snowmelt/Eastern U.S.)

SWE's were measured under white pine, red pine, hardwoods and in a grassy field. Cover types were characterized as to average diameter, basal area and canopy closure. The two coniferous types had similar accumulations as did the hardwood and open types. Snow depth was 5 inches shallower in the former types at the time of maximum accumulation. Lull and Rushmore's (1960) canopy closure vs snow accumulation regression predicted observed depths accurately. The order of snow disappearance was 1) open, 2) hardwood, 3) red pine, and 4) white pine.

91 Haupt, H.F. 1951. Snow accumulation and retention on ponderosa pine lands in Idaho. J. Forestry 49: 869-871.

(Forest Openings, Slope, Canopy Cover, Forest Type/ Snowpack, Snowmelt, Snow Accumulation/U.S. Mountains)

Transects were run on north, south, east, and west aspects. Each station was classified as to mature, pole, sapling, small brush opening or large brush opening. SWE was greatest on the north aspect, least on the south and nearly identical on the west and east slopes. Snowmelt was much less rapid on the north slopes. Haupt attributed the results to "slower melting in early winter and spring on steep north slopes where the sun's rays strike more obliquely and where topographic shading is more prevalent". The greatest SWE occurred in sapling stands and small brush openings on all aspects except the north where large brush openings accumulated the most SWE. The smallest SWE occurred in large brush openings on all slopes except the north. Low accumulations were generally found in mature timber and pole stands. Snowpack on April 15 was related more to accumulation rather than to differential melt rates.

92 Haupt, H.F. 1972. The release of water from forest snowpacks during winter. USDA For. Serv. Res. Paper INT-114. 17 pp.

(/Snowmelt, Snow Depth, Snow Interception/ U.S. Mountains)

Snowmelt through the snowpack was captured with a lysometer. Melt water runoffs were significantly higher in winter under the forest canopy relative to open areas. The majority of this was the result of drip from snow intercepted in the canopy. The reduced maximal snowpacks in the forest may well be partially due to more rapid melt rates of intercepted snow rather than to sublimation and evaporation.

93 Haupt, H.F. 1973. Relation of wind exposure and forest cutting to changes in snow accumulation. Pages 1399-1405 (Vol.2) in: The role of snow and ice in hydrology. Proc. Banff Symp., UNESCO/WMO/IAHS.

(Slope, Wind, Forest Openings/Snow Depth/U.S. Mountains)

Evaluation of the potential of utilizing wind exposure to augment the amount of snow trapped in openings. A sizeable cornice will develop to the lee of an open, treeless ridge if the trees are removed on the downslope, windward slope. Size of the cornice depends upon the width of the windward opening. The origin of the cornice snow is uncertain. If the management goal is to accumulate snow on N (leeward slopes), openings on the windward should be created. If the goal is to keep snow in place, a belt of trees should be retained to separate a windward opening from the ridgetop.

94 Haupt, H.F. 1979. Local climatic and hydrologic consequences of creating openings in climax timber of north Idaho. USDA For. Serv. Res. Paper INT-223. 43 pp.

(Forest Openings, Aspect/Snow Deposition, Snowpack, Snowmelt/U.S. Mountains)

A study of the effects of clearing size on surface wind, precipitation, percolation, snow deposition, ablation, depth and density in northern Idaho. Wind speed increases rapidly within the first 30 ft of a forest edge and thereafter increases more slowly. On south slopes, there were small increases in snowpacks less than 1 TH from the western edge and no increase at greater distances. This may have resulted from the study clearings being located near ridgetops. On north slopes, snowpacks increased in depth exponentially with distance from the western edge of the forest. The snow increment did not seem to have been stolen from the adjacent forest as the Hoover-Leaf hypothesis states. On south slopes, snowfall increased within openings 1-2 TH wide and declined in larger ones. On north slopes, precipitation increased exponentially with distance from the forest edge. In southern clearings, snow melted 10-16 days earlier than in the surrounding forest. On north aspects, snow was present 2-12 days longer than on the forest floor despite faster melt rates.

95 Haupt, H.F. 1979. Effects of timber cutting and revegetation on snow accumulation and melt in north Idaho. USDA For. Serv. Res. Paper INT-224. 14 pp.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

Report on snow accumulations near and in a 34-year-old clear-cut in northern Idaho with records dating from the second year after the cutting. On the north slope, removal of young mature timber resulted in snowpack gains of 19.3 cm (56% increase) during the period 1942-1952. On the south slope, gains were only 7.6 cm (37% increase). This was mostly due to a more porous tree canopy and higher winds which blew intercepted snow from the trees. Snow accumulation on the north slope recovery plot was less for the years 1967-1974 than for the period 1942-1952. This appears to be a result of increased snow interception by the expanding canopies. There was no evident trend in reduced snow accumulation on the south slope clearcut because reestablishment of the stand was progressing very slowly. On the north slopes, snowmelt was much faster from 1967-1974 than from 1942-1952. Crown closure was only 22 % in the cut vs 80% in the mature forest.

96 Heikinheimo, O. 1920. Suomen lumituhoalueet ja niiden metsat. Metsatieteelisen Koelaitoksen julkaisvja (Helsingfors) 3: 1-134.

(Temperature/Snow Interception/Finland)

Vegetation warmer than freezing melts the first snow to hit it. If cold snow continues to fall, the meltwater refreezes into a firm bond.

Not seen - cited in Miller (1964).

97 Hoover, M.D. 1960. Prospects for affecting the quantity and timing of water yield through snowpack management in southern Rocky Mountain area. Proc. Western Snow Conf. 28: 51-53.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

The effects of forest cover on snow accumulation and melt are discussed. In Colorado, cutting all trees increases snowpack 20-30%; partial cutting results in a proportional increase in snowpack. Melt rates increase with snow accumulation. The question is raised as to how much snow in the openings is blown in from surrounding trees. Interception by trees is questioned as an important factor in controlling water yield. Reduced transpiration in clear cut areas may be the answer.

98 Hoover, M.D. 1962. Water action and water movement in the forest. Pages 33-80 in: Forest Influences. Forest and Forest Prod. Study # 15, Food and Agric. Org. of United Nations, Rome.

(Forest Openings/Snow Interception/General)

Pages 34-36 review snow interception by forest cover. The major unanswered questions are a) is the excess of snow in forest openings a result of snow evaporation from tree crowns?, b) was intercepted snow blown or shaken off into the open areas? And c) do wind eddies caused by surrounding trees cause excess snow deposition in openings?

99 Hoover, M.D. 1971. Snow interception and redistribution in the forest. Proc. Int. Semin. Hydrol. Prof. 3: 14-122.

(Keywords to come)

Not seen.

100 Hoover, M.D., and C.F. Leaf. 1967. Process and significance of interception in Colorado subalpine forest. Pp. 213-224 in: W.E. Sopper and H.W. Lull, (eds.). Forest Hydrology. Pergamon Press, New York

(Crown Characteristics, Forest Openings/Snow Interception/U.S. Mountains)

Describes the process by which snow particles are accumulated by foliage during a storm. At the outset, most snow richochets off the needles or slides down them. Snow is first accumulated at the base of the needles. Snow accumulation is facilitated by upward-inclined needles. Once the initial snow is deposited, more snow is retained by cohesion and the accumulation rate accelerates. Snow held solely within the needle space is quickly lost. Large snow masses build where branches and twigs form a close framework allowing bridging to adjacent snow masses. Low air temperature favours maximal accumulation. Riming may be the cause of often reported greater interceptions at temperatures near freezing. Snowfalls of 1.2-1.5 inches load crown surfaces to the maximal extent. Time-sequence photos were taken of a forest and showed that trees retained no snow in their crowns 45% of the winter. It is suggested that intercepted snow is not vaporized but simply redistributed. Snow courses revealed that no more snow was held in the entire area and that increased depths in the open were equalled by decreased depths in the forest. Increased stream-flow after cutting is probably due to other evaporation - transpiration factors.

101 Hoover, M.D., and E.W. Shaw. 1962. More water from the mountains. Pages 246-252. In Yearbook of agriculture. U.S. Dept. Agric., Washington.

(Forest Openings, Elevation, Forest Composition/ Snowmelt, Snow Depth, Snow Interception/U.S. Mountains)

A review paper discussing some of the many conclusions on forest/snow relations as researched at the Fraser Experimental Forest in Colorado. The paper is intended to highlight the research which has taken place and which will continue to take place at the experimental forest. As a result many different relationships are discussed but each only superficially.

102 Horton, R.E. 1919. Rainfall interception. Monthly Weather Review 47: 603-623.

(Keywords to come)

103 Ingebo, P.A. 1955. An instrument for measurement of the density of plant cover over snow course points. Proc. Western Snow Conf. 23: 26-29.

(Canopy Cover/Snow Interception/U.S. Mountains)

Description of a spherical reflecting apparatus (the "ceptometer") for measuring forest canopy above snow courses. The curvature of the reflecting surface incorporates the fact that surrounding forest cover is important as well as cover directly above a station. Figure 2 provides a regression of ceptometer readings (45°) against percentage of maximum accumulation in the open. My (CCS) calculation of the regression is $y = 0.39x + 99.89$ where y is snow accumulation in forest as % of accumulation in the open and x is % cover density.

104 Jaenicke, A.F., and M.H. Foerster. 1915. The influence of a western yellow pine forest on the accumulation and melting of snow. Monthly Weather Review. 43: 115-124.

(Temperature, Aspect, Crown Cover, Forest Openings/Snow Depth, Snowmelt/U.S. Mountains)

An early study of snow accumulation and melt in a large park and the adjacent forest. In the park, snow accumulation was very uniform whereas in the forest, snow accumulation was profoundly influenced by local tree crowns. During the winter, melt was faster in the forest due to higher minimum and mean temperatures. Once the thin layer of snow in the forest was "broken", snowmelt proceeded rapidly. Because melt rate during the winter was faster in the forest, the amount of snow there was less than in the park. There was no difference in snow density between the forest and the park. Spring thaw began when maximum temperatures reached 50°F. Spring melt was very fast in the park; the entire snowpack disappeared in one week. Large drifts persisted for several weeks in the forest. North slopes retained snow far longer than south slopes and forested ones retained it longer than bare ones. Appended are two curiously blinkered reviews by pompous meteorologists.

105 Jeffery, W.W. 1968. Snow hydrology in the forest environment. Pp. 1-19 in: Proc. of the National workshop seminar on snow hydrology, Canadian National Committee - International Hydrological Decade.

(Forest Openings, Canopy Cover/Snowmelt, Snow Deposition, Snow Interception/General)

A very readable account of forest effects on snow cover. The forest is characterized with respect to biomass, surface wind, radiation, and air temperature. Snow

interception and evaporation is then treated at some length. The most important questions with respect to interception are: 1) where does the snow go? and 2) what influence does it have while lodged? With respect to the first question, results are contradictory. Vapour loss is unlikely to be very important. With respect to the second question, the major effect is clearly to increase reflectance of solar radiation from 10% to about 85%. Snow accumulation is briefly treated with special reference to why forest openings accumulate more snow than the forest. The difference cannot be considered wholly attributable to interception. Snowmelt is treated in detail with special emphasis on radiative exchanges.

106 Jeffrey, W.W., and C.R. Stanton. 1968. Snowpack measurements in lodgepole pine stands at low elevations in the Kananaskis River valley, Alberta. Can. Dept. Forestry, Unpubl. Report.

(Forest Openings/Snow Accumulation/Canadian Mountains)

Measurements of snowpack in low elevation lodgepole forests where snow is ephemeral. In forest openings, snow was found on all 18 days sampled. In the adjacent forest, snow was found only on 3 of the 18 occasions.

Not seen - cited in Jeffrey (1968:10) which presents a nearly indecipherable figure depicting these results.

107 Johnson, W.M. 1942. The interceptions of rain and snow by a forest of young ponderosa pine. Trans. Am. Geophy. Union 23: 566-570.

(/Snow Interception/U.S. Mountains)

A study of rain and snow interception in ponderosa pine forests. There was an initial storage of precipitation in the canopy of 0.03 - 0.05 inches. After the crowns had been saturated, almost all precipitation reached the ground. There were no seasonal differences in interception loss; snow was intercepted in the same magnitude as was rain.

108 Jones, G.W. 1975. Aspects of the winter ecology of black-tailed deer (Odocoileus hemionus columbianus Richardson) on northern Vancouver Island. M.Sc. thesis, Univ. of B.C., Vancouver. 78 pp.

(Canopy Cover, Elevation/Snow Depth/Canadian West Coast)

A study of the winter ecology of black-tailed deer on Vancouver Island. Snow depths increased with elevation in both logged and clearcut area. Snow depth in feet (y) was

related to crown closure in % (x) by the following expression:

$$y = 5.69 - 0.07x$$

Crown closure also increased with elevation.

109 Kienholz, R. 1940. Frost depth in forest and open in Connecticut. J. Forestry 38:346-350.

(Forest Composition, Forest Openings/Snow Interception, Snowmelt/Eastern U.S.)

Pine and hemlock stands intercept most light snowfalls but not heavy ones. Wind movement is reduced; hence wind drifting and packing are reduced. The duration of snow cover in conifer stands is lengthened. All of these factors are less obvious in hardwood stands. These effects are least evident in the open. The snow layer has a retardant effect on frost penetration.

110 Kittredge, J. 1948. Forest influences. McGraw Hill Book Co. Inc., New York. 394 pp.

(Canopy Cover, Forest Openings/Snow Deposition, Snowmelt, Snow Density/General)

Chapter XIV is an excellent and influential review of forest effects on snow cover. Topics dealt with are measuring snow, snow density, evaporation of snow, snow accumulation, and snowmelt.

Density of snow decreases with increasing canopy cover. In California, this effect is more noticeable above 7,000 ft. In general, tree crowns reduce snow accumulation. If openings between crowns are small, excess accumulation in these openings will be small or negative. The greatest excess in snow accumulation occurs in openings at least 1 TH in diameter. The degree to which snow disappearance is retarded is related to forest density.

111 Kittredge, J. 1953. Influences of forests on snow in the Ponderosa-subalpine-fir zone of the central Sierra Nevada. Hilgardia 22: 1-96.

(Forest Composition, Canopy Cover, Forest Openings/ Snowpack, Snow Interception, Snow Depth, Snowmelt/ U.S. Mountains)

A classic report of 7 years work on the effects of forest cover on snow. A total of 100 stations sampled 10 forest types of various age, density, species, and cover. New snow had an average density of 10% and was 1-5% higher under tree crowns. From 13-27% of seasonal snowfall was intercepted by forest canopies. The largest percentages

were in the denser types and under crowns. Open screen cutting resulted in greater accumulations than in the open. Maximum snow depths were greater in open areas or in stands with large openings; dates of maximum snow depths were earlier in such areas. Dates of maximum depth were earlier than dates of maximum SWE. The date when snow reached a density of 40%, the percentage at which percolation begins, was earlier in more open areas. Maximum SWE were smallest in the densest stands. Snow was maintained longer on the south side of clearings. Snow evaporation was less under tree crowns. The date of snow disappearance varied inversely with crown coverage within a 20-ft radius.

112 Kittredge, J., H.J. Lougheed, and A. Mazurak. 1941. Interception and stemflow in a pine plantation. J. Forestry 39: 505-512.

(Crown Characteristics/Snow Interception/U.S. Mountains)

Apparently refers only to rainfall. A study of stemflow and interception in an exotic Canary pine plantation in California. Stemflow amounted to 1% of precipitation on average.

113 Klintsov, A.P. 1958. (Snow interception on trees). Priroda 47(2): 128. In Russian.

(Crown Characteristics, Forest Composition/Snow Interception/USSR)

The difference in snow load between pine and spruce (6 and 8 mm respectively) is considered to be due to the greater rigidity of pine branches.

Not seen - cited in Miller (1964).

114 Komarov, A.A. 1963. Some rules on the migration and deposition of snow in western Siberia and their application to control measures. Nat. Res. Counc. Canada, Techn. Transl. 1094 by G. Belkov.

(Wind/Snow Delivery/USSR)

Deposition of snow is dependent on the cube of the difference between initial and final wind velocities.

Not seen - cited in Miller (1964).

115 Kuz'min, P.P. 1961. Melting of snow cover. (Transl. from Russian by E. Vilim. Israel Program for Scientific Transl., Keter Press, Jerusalem, 1972). 209 pp.

(General/Snowmelt/USSR)

A technical monograph on determination of snowmelt. Chapters are presented on theory, methods, and computation techniques. Emphasis is placed on heat-exchange processes and methods of computing components of the heat balance equation. Highly mathematical.

116 Kuz'min, P.P. 1963. Snow cover and snow reserves. Transl. OTS 61-11467, 1963. 140 pp. From Formirovanic Snezhnogo Pokrova I Metody Opredeleniia Snegozapasov, 1960.

(Keywords to come)

Not seen.

117 Larson, F.R., P.F. Ffolliott, and K.E. Moessner. 1974. Using aerial measurements of forest overstory and topography to estimate peak snowpack. USDA For. Serv. Res. Note RM-267. 4 pp.

(Crown Cover, Aspect, Slope/Snowpack/U.S. Mountains)

Points of varying crown cover, aspect and slope were localized on aerial photographs. Snow depth and water equivalent were determined for these points throughout the season. Percentage of peak SWE was determined by regression equations utilizing crown cover, slope and aspect as estimators. Slope and aspect were converted to potential insolation on index date by tables in Frank and Lee (1966, USDA For. Serv. Res. Pap. RM-10). In areas with steep slopes, an equation excluding crown cover predicted with correlation coefficients of 0.51 - 0.46 and standard error about the regression of 11.4 - 11.9%. On relatively flat terrain, the common log of crown cover times average tree height was included yielding correlation coefficients of 0.70 - 0.63 and standard errors of regression of 15.4 - 17.4%.

118 Leaf, C.F., and G.E. Brink. 1973. Computer simulation of snowmelt within a Colorado subalpine watershed. USDA For. Serv. Res. Paper RM-99. 22 pp.

(Canopy Cover, Slope, Aspect, Elevation, Temperature/ Snow Deposition, Snowmelt/U.S. Mountains)

A computer simulation model of 1) winter snow accumulation, 2) energy balance of the snowpack, 3) snowpack condition, and 4) resultant snowmelt. The model consists of three parts: 1) determination of precipitation type (i.e., snow, rain, or a mixture), 2) the melting process and 3) snowpack condition in terms of energy level

and free water. Model inputs are daily incoming shortwave radiation, daily maximum and minimum temperatures, daily precipitation, slope, aspect, elevation, forest cover composition, and cover density. The model is described, sample output provided and FORTRAN coding presented.

119 Love, L.D. 1953. Watershed management in the Colorado Rockies. J. Soil and Water Cons. 8: 107-112.

(Forest Composition, Forest Density/Snowmelt, Snowpack/ U.S. Mountains)

Reviews data of Dunford and Niederhoff (1944) and Goodell (1952). Describes studies of the effect on streamflow of reduced forest canopy interception. Judicious cutting can increase water yield by 15% indefinitely.

120 Love, L.D. 1955. The effect on streamflow of the killing of spruce and pine by Engelmann spruce beetle. Trans. Amer. Geophys. Union. 36: 113-118.

(Crown Characteristics, Canopy Cover/Snow Interception/ U.S. Mountains)

An outbreak of spruce beetle killed Engelmann spruce and lodgepole pine on a considerable portion of a 762 mi^2 drainage in Colorado. Streamflow increased significantly after tree death. This is attributed to reduced interception by defoliated trees.

121 Love, L.D., and B.C. Goodell. 1960. Watershed research on the Fraser Experimental Forest. J. Forestry 58: 272-275.

(Forest Characteristics, Forest Openings, Forest Density/Snowpack, Snowmelt/U.S. Mountains)

A review of work done on the Fraser Experimental Forest in Colorado. All findings are published elsewhere.

122 Lull, H.W., and R.S. Pierce. 1960. Prospects in the northeast for affecting the quantity and timing of water yield through snowpack management. Proc. Western Snow Conf. 28: 54-62.

(Forest Characteristics, Forest Openings/Snow Interception, Snowmelt/Eastern U.S.)

The greatest SWE accumulation occurred in hardwood forests but the greater melt rate reduced this difference by mid-April. Percent interceptions by various species are presented and range from 30% for red pine to 7% for aspen birch. Differential cutting practices had less effect.

123 Lull, H.W., and F.M. Rushmore. 1960. Snow accumulation and melt under certain forest conditions in the Adirondacks. USDA For. Serv. Northeastern For. Exp. Stat. Paper 138. 16 pp.

(Canopy Cover, Forest Composition, Forest Density/ Snowmelt, Snowpack/Eastern U.S.)

A study of snow accumulation in conifer and hardwood stands occurring under virgin, cut and burned conditions in the Adirondacks. More snow accumulated in the hardwood stands and it melted faster. Snow density was significantly greater later in the winter but no trend was evident with forest type. Most melt was at snow densities of 28-31 % which is different from the west where most snowmelt occurs at densities of 40-50%. Canopy closure estimated with spherical densiometer and regressed against snow accumulation gave an r^2 of 0.794 and explained 63 percent of the variation. Each 10 percent increase in canopy closure resulted in reduction of 1/3 inch of SWE. Snowmelt decreased .005 inches of SWE for each increase of 10% in canopy closure (r^2 = .869, 76 percent of variation explained). Canopy closure was closely related to stem density (inches/acre). At any one point in a forest stand, accumulation or melt is not consistently related to overhead canopy. There was no correlation between accumulation or melt and number of trees within 10 feet of the sampling point. The averages within a stand are consistent, however.

124 Lull, H.W., and F.M. Rushmore. 1961. Further observations of snow and frost in the Adirondacks. USDA For. Serv. Northeastern For. Exp. Stat. Note 116. 4 pp.

(Crown Characteristics, Canopy Cover/Snow Interception, Snowmelt, Snowpack/Eastern U.S.)

Eight snow courses were run through hardwood and conifer cover types. Canopy closure was measured with a densiometer. Results were compared with regressions described in the 1960 paper. Predictions of maximum accumulation and snowmelt rates were very close to the observed. Four-foot branches of several conifer species were nailed to a post and snow depth measurements were made. Snow remained on the branches for 69% of the days. Balsam fir caught the most snow (x = 2.13 inches) and hemlock the least (x = 1.18 inches). Snow was lost most easily from hemlock and white pine. Hemlock needles are flexible and point downwards. Snow was initially caught on white pine fascicles and later bent them over to form a platform.

125 Lull, H.W., and F.M. Rushmore. 1961. Influences of forest cover on snow and frost in the Adirondacks. .Proc.

Eastern Snow Conf. 18: 71-79.

(Keywords to come)

Not seen.

126 Lumb, F.E. 1963. Downward penetration of snow in relation to the intensity of precipitation. Meteorol. Mag. 92: 1-14.

(Keywords to come)

Not seen.

127 Martinelli, M. 1960. Creep and settlement in an alpine snowpack. USDA For. Serv. Rocky Mountain For. and Range Exp. Stat. Res. Note 43. 4 pp.

(Aspect, Slope/Snowpack, Snow Depth/U.S. Mountains)

A short note reporting on two experiments designed to detect creep and settlement in an alpine snowpack. The ratio of total creep to total settlement was determined to be about 1 to 2.6 for short slopes with grades of 20 to 56 percent.

128 Martinelli, M., Jr. 1964. Watershed management in the Rocky Mountain alpine and subalpine zones. USDA For. Serv. Res. Note RM-36.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

A review of early research on the effect of subalpine vegetation on snowpack including Bates and Henry (1928, Monthly Weather Rev. Suppl. 30), Wilm and Dunford (1948) and Goodell (1958). Follows with original research on melt in alpine snowfields.

129 Mattoon, W.R. 1909. Measurements of the effects of forest cover upon concentration of snow waters. Forest Quart. 7: 245-248.

(Forest Openings/Snowpack, Snowmelt/U.S. Mountains)

A comparison of snowmelt and accumulation in western yellow pine forests and parks. Snowfall was greater in the forest than the parks because wind carried snow over the gauges in the open. Melting commenced earlier in the forest due to higher average temperatures. In March, snow depth was uniform in the park but patches of ground were visible in the forest. As spring progressed, melt rates became faster in the parks, with the result that snow

disappeared earlier there.

130 Maule, W.L. 1934. Comparative values of certain forest cover types in accumulating and retaining snowfall. J. Forestry 32: 760-765.

(Forest Composition, Shade/Snow Deposition, Snowmelt/ Eastern U.S.)

A study of how stands of various species intercept and retain snow. Comparative light intensities were measured under the various stands with a Clements Photometer. Least depth of snow was recorded under Norway spruce due to the denseness of the crown and the stiffness of the nedles. White pine, with softer needles and more flexible branches allowed more snow to reach the ground and kept the snow the longest. Hemlock seems no better at preventing snowmelt than are hardwoods. Hardwoods permit practically all snow to reach the ground and retard melting only slightly.

131 McKay, G.A., and B.F. Findlay. 1971. Variation of snow resources with climate and vegetation in Canada. Proc. Western Snow Conf. 39: 17-26.

(Forest Composition/Snowpack, Snow Density/General)

A review of the effect of region, topography, and vegetation on snowfall variability in Canada. Means and SD's of snow density and SWE are given for vegetation regions.

132 McLellan, B. 1978. Relationships between elk, snow, habitat use, and timber management in the White River drainage of southeastern British Columbia. Unpubl. ms., 33 pp.

(Forest Openings, Forest Characteristics, Aspect/Snow Depth/Canadian Mountains)

A study of winter habitat preferences by elk in southeastern B.C. Snow depths averaged 22% less on south-facing clear-cuts relative to level ones. Dense immature pine had less snow than mature forest. Selectively cut forest held the most snow throughout the winter.

133 Meagher, G.S. 1938. Forest cover retards snowmelting. J. Forestry 36: 1209-1210.

(Forest Openings, Canopy Cover/Snowmelt/U.S. West Coast)

The course of snowmelt was followed for two years in three Douglas-fir plots; open, partially cut and virgin forest.

In both years, the snow disappeared in the open about one week before it disappeared in the partially cut stand and about two weeks before it disappeared in the old growth forest.

134 Meiman, J.R. 1968. Snow accumulation related to elevation, aspect and forest canopy. Pp. 35-47 in: Proc. of the National workshop seminar on snow hydrology, Canadian National Committee - International Hydrological Decade.

(Elevation, Aspect, Canopy Cover/Snowpack/General)

A literature review dealing with the effects of elevation, aspect, and canopy cover on snow accumulation. Elevation has strikingly different effects on snow accumulation between physiographic areas. Correlations are improved by including between-year and other land surface factors. Aspect has less effect on snow accumulation than elevation. The result is primarily due to melt influence. However, in forest conditions, where melt is minimized, some workers found snow accumulation itself is affected by slope. Canopy influences on snowpack tend to be less than elevational ones. Canopy effects are, however, highly localized. The physical processes involved are still poorly understood.

135 Meiman, J., H. Froehlich, and R.E. Dils. 1969. Snow accumulation in relation to elevation and forest canopy. Unpubl. partial compl. rpt. to Office of Water Resources Res., U.S. Dept. of Interior.

(Elevation, Canopy Cover/Snowpack/)

Only 32% of the variance in spring SWE was accounted for by elevation and crown cover. Year to year relative accumulations at single points were highly variable.

Not seen - cited in Dietrich and Meiman (1974).

136 Merriam, H.E. 1971. Deer report. Progr. Rpt. Fed., Aid Wildlife Rest. Proj. No. W-17-1. Vol. X. Alaska Fish and Game, Juneau. 30 pp.

(Forest cover/Snow Depth/U.S. West Coast)

Snow is twice as deep in openings as in mature timber in southeast Alaska.

Not seen - cited in Regelin (1979).

137 Miller, D.H. 1955. Snow cover and climate in the Sierra Nevada California. Univ. of Calif. Geog. Publ., Vol. II. 218 pp.

(Canopy Cover, Crown Characteristics, Forest Type// U.S. Mountains)

A broad-ranging study on the effects of snow on the climate of the Sierra Nevada which, though having an extensive and long-lasting snow mantle, does not exhibit the heat-balance of a typical snow-influenced area. Chapter III deals with the effect of open forest on local climate and Chapter IV treats the physics of snow cover. The section on insolation transmission through the forest canopy is particularly important. Fruitless attempts to develop linear or curvilinear relationships between crown closure and transmission suggests the crown mass is the critical measure. Stem density is more closely related to transmission than is basal area or crown closure. Crown closure as a physical measure is untenable.

138 Miller, D.H. 1959. Transmission of insolation through pine forest canopy, as it affects the melting of snow. Mitt. Schweiz. Anst. Forstl. Versuchswesen. 35: 57-79.

(Forest Openings, Forest Density, Canopy Cover/ Snowmelt/General)

A refinement and extension of the section on transmission of insolation presented by Miller (1955). He argues that heat balance methods estimate melt rates much better than temperature. Attempts to relate transmission to crown closure produced wide scatter (Fig.1, p.64) [but most of the values for crown closure were estimated by Miller from author's statements]. Miller suggests that some of the departures from the expected relationships were likely caused by differences in crown depth; even sparse crowns intercepted radiation by absorption in depth. Extinction coefficients for forest canopies are provided. The relationship between transmission and stem density (inches/acre; i.e., BA) was tighter (Fig.2, p.67), than that with crown closure.

Melting rates in forested and open sites are related to available heat surplus or transmission of insolation. Problems and suggestions for field work that would treat the physical dimensions of stands are offered.

139 Miller, D.H. 1961. Folklore about snowfall interception. Trans. Amer. Geophys. Union. 42: 229.

(/Snow Interception/)

An unpublished paper presented at the 42nd Annual Meeting

of the American Geophysical Union. Its existence is mentioned but the contents are not described. From Magnuson (1962), we deduce its contents are presented in Miller (1962).

140 Miller, D.H. 1962. Snow in trees - where does it go? Proc. Western Snow Conf. 30: 21-27.

(Temperature, Wind, Crown Characteristics/Snow Interception/General)

A discussion of the movement of snow intercepted by tree canopies. Wind is less of an agent in snow removal than it might appear. Unless strong winds follow snowstorms directly, snow masses resist mechanical removal. Partial melting may occur which causes snow masses to slide off the foliage. It is likely that < 1/4 of the snow mass is melted before it slides off. Meltwater leaving the crowns as stemflow is thought to be small in conifers and possibly moderate in deciduous trees; it is more important in maritime climates. Sublimation requires much more energy than melting. Sublimation is often considered to be the major source of snow removal from crowns; however, that seems unlikely due to lack of sufficient heat influx. More data are required.

141 Miller, D.H. 1964. Interception processes during snowstorms. USDA Forest Serv. Res. Pap. PSW-18.

(Crown Characteristics, Forest Composition, Temperature, Wind/Snow Interception/General)

A discussion of how vegetation intercepts snowfall. Broken down into 4 main topics: a) delivery of snow, b) throughfall of particles to the forest floor, c) impaction and adhesion of particles to the foliage, and d) cohesion of particles into snow loads. Delivery of snow is nearly horizontal (4° from horizontal). Snow falls at less than one m sec^{-1}; about 1/8-1/10 the velocity of raindrops. The low angle of incidence has the effect of increasing crown surface. For this reason, crown coverage in two dimensions is a poor predictor of snow penetration. Perhaps selective logging increases snow penetration less by opening the canopy than by removing dominant trees. Deposition of snow depends on the cube of the difference between initial and final air velocities; therefore, even small wind decreases can result in large depositions. Understanding snow delivery requires conceptualizing the canopy as seen from above. Micrometeorological study of the canopy suffers from lack of reproductibility - there are no measures adequate to handle the variability. True throughfall, penetration of canopy without alighting on branches, is analogous to solar penetration. At temperatures near freezing, one degree Celsius of warming

can increase interception by 30% due to greater adhesion. High winds drive snow into the canopy but also dislodge it. Dry snow is most easily dislodged. Roughness of the surface of the twigs, branches and leaves affect adhesion. Flexibility of the foliage determines how much adheres. Volume of foliage plays a role in interception but this is still undefined. From Kittredge's (1948) data, it is calculated that 0.1 cm^{-3} of water is held on 3 cm^{-2} of leaf area as snow. Foliage weight is near 0.1 g cm^{-2} of ground surface whereas 2 mm of snow load is 0.2 g cm^{-2} - a load ratio of 2:1 which is much less than severe ice storms. Bare winter hardwoods may intercept considerable snow although many workers report little interception. This has implications for snow breakage. After the first layer of snow has adhered to the foliage, further accumulation is a function of the cohesion of snow particles. Cohesion may be by friction or sintering. Cohesion must overcome gravity and wind. Wind may increase cohesion. Maximum adhesion and cohesion occur near the freezing point. Research needs are outlined.

142 Miller, D.H. 1965. Sources of thermodynamically-caused transport of intercepted snow from forest crowns. Pages 201-212 in: Wm. E. Sopper and H.W. Lull, (eds.), Forest Hydrology. Pergamon Press.

(General/Snow Interception/General)

Suggestions for research approaches to the heat budget of intercepted snow.

143 Miller, D.H. 1966. Transport of intercepted snow from trees during snow storms. USDA For. Serv. Res. Paper PSW-33. 30 pp.

(Forest Composition, Crown Characteristics, Canopy Cover, Forest Openings/Snow Interception/General)

It has proven difficult to find simple, universally applicable relations between snowfall in forested and unforested areas. The failure suggests that the process is not a unitary phenomenon but a series of processes each of which must be described and quantified. This paper supplements Miller (1964) is examing five basic processes by which intercepted snow is transported from tree branches. Part I treats wind erosion. Part II deals with snow sliding from the branches as the twigs bend under the snow load. The triggering action for snow drop may be an external disturbance or melting of the ice bonding the snow to the sloping surface. Part III treats stemflow and drip. This process has been reported to be negligible by some and very significant by others. The last two processes treated are vapour transport from melt-water and from the snow itself. Pages 17-21 deal with factors

affecting the differences between snow accretions in the forest and nearby open areas; a quantity termed 'A'. Forest factors influencing 'A' do not group well into any classification. An extensive review of forest effects on 'A' is provided.

144 Miner, N.H., and J.M. Trappe. 1957. Snow interception, accumulation, and melt in lodgepole pine forests in the Blue Mountains of eastern Oregon. USDA For. Serv. Res. Note PNW-153. 4 pp.

(Forest Openings, Forest Density/Snowpack, Snowmelt/ U.S. Mountains)

Studies were done in a mixed Oregon forest of 700 trees acre^{-1} with an average d.b.h. of 11 inches. Gauges in forested plots caught 76% as much snow as gauges in small openings. Snow depth in the forest averaged 62% that of the meadow. Snowmelt proceeded at 0.30 inches day^{-1} in the meadow and 0.12 inches day^{-1} under the forest. The snow lasted as long in the open due to greater accumulations.

145 Mixsell, J.W., D.H. Miller, S.E. Rantz, and K.G. Brecheen. 1951. Influence of terrain characteristics on snow pack water equivalent. Res. Note No. 2, Coop. Snow Investig. So. Pac. Div. Corps of Eng., U.S. Army, San Francisco. 9 pp.

(Keywords to come)

Not seen.

146 Molchanov, A.A. 1963. The hydrologic role of forests. Transl. from Russian by Israel Prog. Sci. Transl., IPST Cat. No. 870.

(Forest Type/Snow Interception/USSR)

Chapter II is an extensive review of the older literature on precipitation (primarily rainfall) interception by forests. It is repeatedly stated that the percentage of interception depends upon the heaviness of the rainfall or snowfall. Figure 4 is a graph of snow and rain penetration of the crown as a function of stand age. Percentage penetration drops off steeply with increasing stand age until about 35 years and then increases slowly up to a stand age of 166 years where it is about 90%. A large quantity of data describes precipitation interception in deciduous forests and describes bole runoff.

147 Morey, H.F. 1942. Discussion of: W.M. Johnson, the interception of rain and snow by a forest of young ponderosa pine. Amer. Geophys. Union Trans. 23: 569-570.

(Canopy Cover, Crown Characteristics, Forest Density, Forest Type, Forest Composition/Snow Interception/ Eastern U.S.)

A correlation may exist between snow interception in Vermont and crown-density, stem-density and stem-size. Sapling size conifers have dense but thin crowns whereas older stands all have less dense but thicker crowns. Snow interception is greater in the former. Even small holes in the canopy allow large accumulations. Forests with a well developed understory intercept more snow. Each storm must be treated individually because of the many important characteristics affecting interception. Water storage in the form of snow interception is 0.08 inches in mature hardwood and 0.36 inches in 30 year-old red spruce.

148 Nasimovich, A.A. 1955. The role of the regime of snow cover in the life of ungulates in the USSR. Muskva Akad. Nauk SSR. 403 pp. Transl. from Russian by the Canadian Wildlife Service, Ottawa.

(Forest Composition, Canopy Cover/Snow Depth/USSR)

Pages 68-69 discuss the effect of forest stands on snow depth. Ifn one area in the Caucasus, snow depths varied by 270 cm within 500 m due to forest type and density. Snow depth is most variable in mountain regions.

149 Niederhof, C.H., and E.G. Dunford. 1942. The effect of openings in a young lodgepole pine forest on the storage and melting of snow. J. Forestry 40: 802-804.

(Forest Openings, Forest Density/Snowpack, Snowmelt/ U.S. Mountains)

Snow measurements were made within natural openings of various sizes in lodgepole pine of two densities. Maximum accumulations occurred in openings of approximately one TH. More snow was accumulated in openings in the dense forest than in openings in the open-grown forest (this may be an artifact). Snow was maintained longest in openings of about one TH. Snow accumulated most and remained longest in the southern half of the openings.

150 Packer, P.E. 1960. Some terrain and forest effects on maximum snow accumulation in a western white pine forest. Proc. Western Snow Conf. 28: 63-66.

(Elevation, Aspect, Canopy Cover/Snowpack/

U.S. Mountains)

Elevation has the greatest effect on snowpack in Idaho. The next greatest effect is aspect - snowpack increases clockwise from 165° to 11°. The aspect effect is greater at high elevations. The between-year effect was the next most important while forest canopy effects were the least important. The SWE increased by 4.2 inches (32%) with decreases from 100-0% canopy cover. This relation was uniform regardless of year, elevation or aspect. This loss is therefore primarily due to interception rather than differential melting.

151 Packer, P.E. 1962. Elevation, aspect, and cover effects on maximum snowpack water content in a western white pine forest. Forest Science 8: 225-235.

(Canopy Cover, Forest Openings, Elevation, Aspect/ Snowpack/U.S. Mountains)

Similar to Packer (1960). A study of the effects of logged openings in the forest canopy and DBH on snow storage. Elevation had the greatest effect on SWE. Maximum and minimum SWE's occurred at aspects of 11° and 165° respectively with a point of inflection near true west. This effect was greater at higher elevations. The SWE decreased 4.2 inches as the canopy cover was reduced from 100% to 0% in large openings. This relation was uniform with respect to year, elevation, and aspect. This was considered to be due to interception rather than melt. Canopy cover data are transformed to correspond to Wellner's (J. For. 46: 16-19; 1948) analysis relating canopy cover to cumulative diameter and basal area. Snowpack was found to be related to these latter measures curvilinearly; snowpack dropped off steeply at high stand densities.

152 Packer, P.E. 1971. Terrain and cover effects on snowmelt in a western white pine forest. For. Sci. 17(1): 125-134.

(Forest Density, Crown Closure, Aspect, Elevation, Slope/Snowmelt/U.S. Mountains)

Snowmelt rates were studied over 4 years. Differences in elevation, aspect, slope steepness, forest cover and air temperature accounted for 74% of the variance in melt rate. For every 100 ft elevational increase, snowmelt was delayed by 1.2 days and rates decreased 0.014 inch day^{-1}. The effect of slope was 4 times greater at 5,500 ft elevation than at 2,700 ft. Slope had a major effect on melt rate depending upon elevation and aspect. From 160-280°, steep slopes began melting later, from 280-40°, they began melting earlier. Each 10% increase in forest

density postponed snowmelt 1.1 days on the south slope and 0.4 days on the north slope. The effect of forest density on snowmelt rates was influenced by aspect and elevation in a complex manner. At low elevations, snowmelt rates decreased with increasing crown closure at all aspects. At high elevations, snowmelt rate increased with increasing crown cover. On southern aspects it increased with closure over the range of closure from 25-100%. This occurs because melt rate begins later in the forest at high elevations and then proceeds very rapidly. Cumulative diameter and basal area of the forest stand exhibit comparable relations with snowmelt.

153 Pierce, R.S., H.W. Lull, and H.C. Storey. 1958. Influence of land use and forest conditions on soil freezing and snow depth. For. Sci. 4: 246-263.

(Forest Type, Forest Composition/Snow Depth/Eastern U.S.)

Frost penetration in hardwood stands was about half that in conifer stands. One reason for this finding was the greater snow accumulation in hardwood stands. Table 8 gives ratios of snow depth in forests of various types relative to snow depth in the open.

154 Pruitt, W.O., Jr. 1958. Qali, a taiga snow formation of ecological importance. Ecology 39: 169-172.

(/Snow Interception/Arctic-Subarctic)

Qali is Kobuk Valley 'Eskimo' term for "snow that collects on trees". Formation depends upon 1) lack of wind, 2) low quantities of solar radiation, 3) continuous low ambient temperatures. Description of a "qalimeter" (a collection of birch dowels of varying thickness) and collection of snow on the instrument. The argument is made that much of what is commonly interpreted as wind-throw is actually due to qali accumulation.

155 Rosenfeld, W. 1944. Erforschung der Bruchkatastrophen in den Ostschlesischen Beskiden in der Zeit von 1875-1942. Forstwiss. Centbl. und Thar. Forstl. Jahrb. 1: 1-31.

(Wind, Aspect/Snow Interception/Europe)

Wet snow overbalances trees so they lean. They then collect more snow and often break. In the catastrophic break of 1888 in Siberia, 2/3 of the damage was in the calm windshadow of the S and E slopes.

Not seen - cited in Miller (1964).

156 Rothacher, J. 1965. Snow accumulation and melt in strip cuttings on the west slopes of the Oregon Cascades. USDA For. Serv. Res. Note PNW-23. 7 pp.

(Forest Openings/Snowpack, Snow Depth, Snowmelt/ U.S. Mountains)

Six strips, two chains wide and 15 long, were cut in uniform hemlock-fir forest in Oregon. Snow depth and SWE were higher (23% and 35% for depth and SWE respectively) in the stripcuts but, due to higher melt rates, snow disappeared earlier on the cuts. Sample plots 3.00, 3.75 and 4.50 chains into the forest showed no differences in snow depth or SWE.

157 Rowe, P.B., and T.M. Hendrix. 1951. Interception of rain and snow by second-growth ponderosa pine. Trans. Amer. Geophys. Union 32: 903-908.

(/Snow Interception/U.S. Mountains)

Of a total annual precipitation of 47 inches, 84% reached the forest floor as throughfall, 4% as stem flow while 12% was lost by interception. About 4% more precipitation reached the forest floor during snowstorms than rainstorms.

158 Sartz, R.S., and G.R. Trimble, Jr. 1956. Snow storage and melt in a northern hardwood forest. J. Forestry 54: 499-502.

(Forest Openings/Snow Depth, Snow Density, Snowmelt, Snowpack/Eastern U.S.)

Three openings were made in pole sized stands and one in a saw timber stand in mixed deciduous forest in the White Mountains of New Hampshire. All were on gentle north slopes and were about 2 TH wide at the widest point. Snow was 21-28% deeper in the openings. The SWE equivalent differences were not as large as the snow depth differences because densities in the woods were 18-26% greater. The best explanation for this observation is absorption of sunlight by the boles and subsequent reradiation. Melt rings appeared early around the boles. There was a forest edge effect about 10 feet wide outside and inside the forest edge. The fastest melt was on the north side of the clearings, the next fastest in the woods and the slowest on the south side of clearings where sunlight and reflected heat were minimal.

159 Satterlund, D.R., and A.R. Eschner. 1965. The surface geometry of a closed conifer forest in relation to losses of intercepted snow. USDA For. Serv. Res. Paper NE-34.

16 pp.

(Crown Characteristics, Wind/Snow Interception, Snowmelt/General)

An examination of snow interception processes with respect to the differences in heat transfer between open, level ground, and the complex geometry of forest canopies. Albedos of 90% measured in the open may be reduced significantly by multiple reflection in a complex canopy. Turbulent heat and vapour transfer equations are markedly influenced by a "roughness parameter". This parameter is obtained by plotting wind speed at several elevations above a given surface against height. The curve is then extrapolated to zero wind velocity and the height intercept denotes the roughness parameter. This roughness parameter is adequate to account for higher evaporation losses from conifer stands relative to open fields.

160 Satterlund, D.R., and H.F. Haupt. 1967. Snow catch by conifer crowns. Water Resources Research 3: 1035-1039.

(Crown Characteristics/Snow Interception/U.S. Mountains)

Trees were continuously weighed during snow storms to measure snow catch. Graphing snow catch vs snowfall gave a uniform sigmoid form. A general equation for snow catch is given based on the Lotka growth function. The first snowflakes fall through the branches and needles; only a few adhere giving a low growth rate. As snow bridges across needles develop, more and more snow is caught on the ever-growing platforms. The catch rate therefore increases until heavy snow loads cannot be borne with the excess sliding off. The size, form and wetness of the snowflakes determine the catch rate while the form, surface area, and strength of branches determine the ultimate snow load. This process is fundamentally different than rain interception.

161 Satterlund, D.R., and H.F. Haupt. 1970. The disposition of snow caught by conifer crowns. Water Resources Research 6: 649-652.

(Crown Characteristics/Snow Interception/U.S. Mountains)

A continuous weight record was obtained for snow load on suspended trees (Douglas-fir and white pine). About 1/3 of the snowfall was temporarily intercepted. Losses to the atmosphere were 4.5 and 5.2% for Douglas-fir and white pine respectively. About 86% of the snow ultimately reached the ground. The greatest quantity (46%) was washed off by rain. Large mass release accounted for 25% of the loss and minor mass release and drip accounted for the remainder. There were no species differences despite

obvious differences in needle structure and branches.

162 Schaerer, P. 1970. Variation of ground snow loads in British Columbia. Proc. Western Snow Conf. 38: 44-48.

(Elevation/Snowpack/Canadian West Coast, Canadian Mountains)

A study in the variability in SWE (and ground load) vs elevation in British Columbia. The wetter the climate, the stronger is the increase in snowload with elevation. In dry, cool areas, the increase is more linear. The curve shapes are similar from year to year.

163 Schielderup-Poulson, H. 1954. Solstralens betydning for smelting av sne og is. Naturnen 79: 66-73.

(/Snowmelt/General)

Snowmelt was determined to be caused 81% by short-wave radiation, 15% by heat, 3.5% by condensation of moisture, 0.2% by rain, and 0.3% by evaporation.

Not seen - cited in Skogland (1978).

164 Seppanen, M. 1959a. On a new method of measuring snow cover in forest in Finland. Int. Assoc. Sci. Hydrol. 48: 248-251.

(Forest Density/Snowpack, Snow Interception/Europe)

An incomprehensibly written report of an investigation into the effects of single trees on point SWE determinations. SWE's were measured on a grid in the forest. The number of trees/400m^2 was calculated for the forest as a whole and for the area surrounding the point measurement. The percent increase in SWE per tree less than or greater than the mean tree density was calculated. A curvilinear relation was found between this index and mean tree density. At mean tree densities of 16/400m^2, local variations in tree density had no effect on SWE. At mean densities less and greater than 16 trees per 400m^2, SWE decreased and increased respectively in local dense patches.

165 Seppanen, M. 1959b. On the quantity of snow lodging on branches of trees in pine dominated forest on January 16, 1959, during the time of snow destructions in Finland. Int. Assoc. Sci. Hydrol. 48: 245-247.

(/Snow Interception/Europe)

An average of 2,600 kg per 100m² was held in the branches of pine forests of normal thickness. No indication is given of measurement techniques or what is meant by "normal thickness".

166 Seppanen, M. 1961. On the accumulation and the decreasing snow in pine dominated forest in Finland. Fennia 86: 1-51.

(Keywords to come)

Not seen.

167 Shidei, T. 1954. Studies on the damages on forest tree by snow pressures. Japanese Gov't. For. Expt. Sta. (Meguro), Bull. 73. 89 pp. (in Japanese with English summary)

(Temperature, Wind/Snow Interception/Japan)

The snow crown becomes heaviest at night when air temperature is near freezing and there is no wind or net downward radiation.

Not seen - cited in Miller (1964).

168 Silver, R.S. 1976. Ecological features of moose (Alces alces andersoni) winter habitat in the boreal white and black spruce zone of northeastern British Columbia. M.Sc. thesis, Univ. of British Columbia, Vancouver. 278 pp.

(Canopy Cover, Forest Composition/Snow Depth/Boreal Canada)

Snow depth was measured at 10 stations near Ft. St. John, B.C. Canopy cover was determined with a dot-grid overlay of photos taken with a fish-eye lens. Deciduous vegetation was ineffective at intercepting snow despite dense crown closures; black spruce showed the largest snow accumulation.

169 Singer, F.L. 1979. Habitat partitioning and wildlife relationships of cervids in Glacier National Park. J. Wildl. Manage. 43: 437-444.

(Forest Composition/Snow Depth/U.S. Mountains)

In Montana, open types had mean snow depths of 80 cm. Douglas-fir and spruce forests had mean snow depths of 12 and 40 cm respectively.

170 Smith, J.L. 1974. Hydrology of warm snowpacks and their effects upon water delivery... Some new concepts. Pages 76-89 in: J.L. Smith (ed.), Advanced concepts and techniques in the study of snow and ice resources. Nat. Acad. Sci., Wash., D.C.

(Crown Characteristics, Forest Openings, Forest Composition, Forest Type/Snowpack, Snow Interception, Snowmelt/U.S. Mountains)

Prefaced with an excellent historical review of research on the effects of forests on snowpack. Old theories, originated by Kittredge, assumed differences in snowpacks in the forest and open areas due to wind and evaporation-sublimation of intercepted snow. New theories suggest forests have no effect on the amount of water reaching the ground and that observed snowpack differentials are due to continuous, differential melt of the snowpack and to drip and stemflow. Observations during snowstorms indicate that snow is deposited uniformly across openings. Differential snowpacks in various quadrats of the openings are due to "back radiation" from trees on the sunny border. Data are given to support this contention. On moderate north and south slopes, the greatest melt is in the east and north quadrats of the openings. On true south slopes, however, snowmelt is slower in open areas late in the year. It is theorized that on south slopes, the sun dwells longer on dense forest and causes greater heat storage and therefore faster melt rates in the forest. Evaporation of snow from tree crowns is significant only under unusual atmospheric conditions. Fir branches are flexible. They drop and deposit their snow load and drip in a narrow ring 3-6 ft from the stem. Lodgepole pine have stiff boughs and snow and meltwater drop from point of storage. Therefore, SWE in fir stands is only 60-70% of the the open whereas in pine stands, it is 93-97% of the open. Snow in the open has more profile layering.

171 Solomon, R.M., P.F. Ffolliott, and J.R. Thompson. 1976. Correlation between transmissivity and basal area in Arizona ponderosa pine forests. USDA For. Serv. Res. Note RM-318. 3 pp.

(Forest Density/Snowmelt/U.S. Mountains)

The study attempts to create an empirical index of transmissivity by regressing daily insolation on basal area and stem density. The authors argue that transmissivity is the primary variable controlling the amount of short- and long-wave radiation available at the snow surface and thus controls snowmelt. Therefore an index of transmissivity would be helpful in predicting snowmelt. A logarithmic transformation of the basal area regression was suggested as the best relationship (r =

0.794):
Log (TR) = 2.144 - 0.229 log BA
where TR = transmissivity in percent
BA = basal area in ft^2/ac.

172 Stanton, C.R. 1966. Preliminary investigation of snow accumulation and melting in forested and cut-over areas of the Crowsnest Forest. Proc. Western Snow Conf. 34: 7-12.

(Forest Openings, Aspect/Snowpack, Snowmelt/Canadian Mountains)

Table 1 presents March 25 SWE on paired cut and uncut areas of various aspects. Differences ranged from 6.5 - 22.5 inches (3-46.4%) with the cut areas always accumulating the most snow. Melt rate from March 25 - June 3 was faster by 12-23% in the cut areas. Cut areas were therefore free of snow slightly in advance of uncut areas despite an initially larger snowpack. Water equivalents were 6.1-64.5% higher in the cut-over areas. The elevational effect was an increase in SWE of 1.5 inches per 100 ft. Snow depths were greater in the centre of clear-cuts. On the north-facing cuts, there was a noticeable accumulation of snow right at the edge.

173 Stures, D.L. 1977. Snow accumulation and melt in sprayed and undisturbed big sagebrush vegetation. USDA For. Serv. Res. Note RM-348. 6 pp.

(Crown Characteristics/Snowpack, Snowmelt/ U.S. Mountains)

Snow accumulation and melt were very similar in untreated and defoliated sagebrush plots.

174 Swanson, R.H., and D.R. Stevenson. 1971. Managing snow accumulation and melt under leafless aspen to enhance watershed value. Proc. Western Snow Conf. 39: 63-69.

(Forest Composition, Canopy Cover, Forest Openings/ Snowpack, Snowmelt/Canadian Mountains)

Use of aerial and ground photographs to demonstrate that leafless aspen and willow stands are effective in accumulating snow and retarding its loss. Small openings in leafless canopies are effective snow traps; 1/3 more snow accumulated in small openings and was lost (ablated) 30% more slowly. Openings had three zones of influence: the opening itself, the fringe 1 TH in and out of the opening, and under the canopy. Reported ablation rates under the hardwood canopy were slower than under conifers. Margins of openings retained snow two weeks longer than the canopy. Tree cover 'protected' snow from chinook

winds.

175 Tikhomirov, E. 1938. Snow interception and snow-break in forests. Meteorologicheskii Vestriik 1934 (1/3): 50-52. (in Russian)

(Temperature/Snow Interception/USSR)

Wet snow clings to trees more than dry snow. Cold trees and warm snow leads to the adhesion of large snow masses.

Not seen - cited in Miller (1964).

176 Trimble, G.R. Jr. 1956. A problem analysis and program for watershed management research in the White Mountains of New Hampshire. USDA For. Serv. Northeast Forest Exp. Stat. Paper 116. 46 pp.

(Forest Composition/Snow Interception, Snowmelt/Eastern U.S.)

Within a larger problem analysis, contemporary knowledge about snow interception and melt is reviewed. The average snow interception by various forest types in the White Mountain area of Vermont is expected to be as follows: northern hardwoods, 10%; aspen-birch, 7%; spruce or spruce-fir, 35%; white pine, 25%; hemlock, 25%; and red pine, 30%.

177 United States Army. 1956. Snow hydrology: summary report of the snow investigations, North Pacific Division, Corp of Engineers, United States Army, Portland. OR. 437 pp.

(Canopy Cover/Snow Interception/General)

A major compendium of research findings on snow hydrology based on 12 years of research by many workers. Of particular importance is section 4.03 (Interception Loss). Page 47 gives regression equations relating SWE under the canopy as % of SWE in open (y) to % canopy cover (x).

$$Y = (95.5 \text{ to } 99.9) - (0.359 \text{ to } 0.401)\ x$$

Figures 5 and 6 on Plate 4-11 present these regressions graphically.

178 Vezina, P.E. 1964. Solar radiation available over snow pack in a dense pine forest. Agr. Meteorol. 1: 54-65.

(Canopy Cover/Snowpack/Boreal Canada)

179 Watanabe, S., and Y. Ozeki. 1964. Study of fallen snow on forest trees (II). Experiment on the snow crown of the

Japanese cedar. Japan Government Forest Experiment Station Bull. 169: 121-140.

(Crown Characteristics/Snow Interception/Asia)

Trees were continuously weighed during snowstorms. The weight of snow intercepted by trees was proportional to the length of their limbs. Two varieties of the same species exhibited different patterns of crown deformation. The variety from a snowier region had more flexible branches and carried 3 mm less of a snow load. Trees were shortened and thinned by pruning; the weight of intercepted snow was reduced proportionately to the decrease in volume of the crown in the shortened trees. Thinned crowns held even less snow suggesting that the absence of branches within the crown curtailed the opportunity to hold snow.

Not seen - cited in Miller (1964).

180 Weitzman, S., and R.R. Bay. 1959. Snow behavior in forests of northern Minnesota and its management implications. USDA For. Serv. Lake States For. Exp. Stat. Paper 69. 18 pp.

(Forest Openings, Forest Composition/Snowpack, Snowmelt/ Eastern U.S.)

Snow accumulation and melt were studied under different canopies within a forest type and between forest types. Snow accumulation was greatest under the aspen stand followed by red pine stand thinned to 60 ft^2 $acre^{-1}$. These were followed by red pine thinned to 100 and 140 ft^2 $acre^{-1}$. Snow disappeared in the opposite order. Black spruce accumulated the most snow in clearcuts and strip cuts, followed by "shelterwood" with an open canopy and tree selection plots with smaller openings. Snowmelt was in the following order (fastest to slowest): open, shelterwood, tree selection, strip, and uncut. East-west strips captured the most snow and retained it the longest.

181 West, A.J. 1959. Snow evaporation and condensation. Proc. Western Snow Conf. 27: 66-74.

(Forest Openings/Snowmelt/U.S. Mountains)

Normal daytime evaporation is greater in the open than under the forest canopy by about 2 times. At night there is more evaporation in the forest. Larger openings had larger evaporation rates than small openings. Snow losses due to evaporation are a small part of the total pack.

182 West, A.J. 1961. Cold air drainage in forest openings. USDA For. Serv. Res. Note PSW-180.

(Forest Openings, Aspect, Slope, Temperature/Snowpack, Snow Depth/U.S. West Coast)

This note reports results of a study concerning the accumulation of snow in the downslope segment of small forest openings. Maximum snow accumulation always occurred in the downslope segment and four possible explanations were tested; snow creep, water drainage, evaporation, and evaporative cooling. Of these, evaporative cooling was determined to have the greatest effect on the snowpack.

183 West, A.J. 1962. Snow evaporation from a forested watershed in the Central Sierra Nevada. J. Forestry 60: 481-484.

(Forest Openings, Canopy Cover/Snowmelt/U.S. Mountains)

Snow evaporation in forested areas was about 1/2 that in open areas. Evaporation losses increased with opening size apparently due to greater wind speeds in larger openings. A forest stand of 50-80% density had 25% more evaporation than a 20-50% stand again due to differences in wind speed.

184 Wilm, H.G., and M.H. Collet. 1940. The influence of a lodgepole pine forest on storage and melting of snow. Trans. Amer. Geophys. Union 21: 505-508.

(Canopy Cover/Snow Accumulation, Snowmelt/ U.S. Mountains)

A study of the effect of natural differences in lodgepole pine stand density on snow accumulation and melt. SWE was greater further away from tree crowns; the correlation coefficient (r) between SWE and distance to crown edge was 0.493 for 1938 and 0.430 for 1939. An index of storage duration was also related to crown density; a combination of distance to canopy edge and exposure resulted in r values of 0.528 and 0.529 for the two years. All of these relationships were linear indicating that openings as large as 30 feet in radius may be needed for maximal snow accumulation and storage.

185 Wilm, H.G., and E.G. Dunford. 1948. Effects of timber cutting on water available for streamflow from a lodgepole pine forest. USDA For. Serv. Tech. Bull. 968. 43 pp.

(Forest Density/Snowpack, Snowmelt/U.S. Mountains)

Original not seen, but from Colman (1953) and Miner and Trappe (1957) we note: Study area - virgin, upper lodgepole pine zone at the Rocky Mountain crest, Colorado; Objective - determine effects of several intensities of forest cutting on amounts of water available from stream flow. Water yield was deduced by measurements of snowpack, evaporation, and interception throughout the year. Four intensities of cutting and control plots were used. Amounts of snow reaching the ground increased progressively with increasing intensities of cutting. Contrary to other studies, there was no difference in length of the snowmelt period between treatments. Apparently the greater depths of snow that accumulated in more open areas were compensated for by more rapid melt.

186 Wilson, R.G. 1970. Topographic influence on a forest microclimate. Climatological Research Series No. 5. McGill Univ., Montreal. 109 pp.

(Aspect, Elevation, Slope, Temperature//)

A 17-month study defining the topoclimate within a hardwood forest on Mount St. Hilaire, Quebec. Objectives were to quantify energy and water balances on a north slope, south slope, and a level plane. The findings are peripherally, but strongly related to forestry: snow relationships. Interception was not measured, but the monograph presents a detailed treatment of the theory and observations relating to energy balance. The general relationships presented (between slope, aspect, canopy cover, and energy balance) are applicable to any consideration of heat balance within a snowpack.

187 Wilson, W.T. 1954. Analysis of winter precipitation observations in the cooperative snow investigations. Monthly Weather Rev. 82: 183-195.

(Keywords to come)

188 Woo, M. 1972. Numerical simulation of snow hydrology for management purposes. Ph.D. thesis, Univ. of British Columbia, 161 pp.

(Canopy Cover/Snow Interception/Canadian West Coast)

Development of a simulation model for snow storage and melt-water release for small mountain basins in the UBC Research Forest. Daily precipitation and temperature are the driving variable. These are inputted as both random and deterministic variables. The model is tested against 100 years historical records and performs adequately. Snowfall in the forest (Sf) is related to snowfall in the open (So) by the following relation:

$$Sf = 0.0101\ So^2 \text{ for } Sf \leq So$$

A short tabular review of snow interception literature is provided.

189 Zinke, P.J. 1967. Forest interception studies in the U.S. Pages 137-161 in: Wm.E. Sopper and H.W. Lull (eds.), Forest Hydrology. Pergamon Press, New York.

(General/Snow Interception/General)

A thorough mathematical review of rain and snow interception studies from a hydrological perspective. A glossary of American terminology is included. The summary on snow interception is essentially that of Kittredge (1948,1953).

190 Zon, R. 1927. Forests and water in light of scientific investigation. In U.S. Nat. Waterways Commission Final Report. Senate Document 469. 62nd Congress, 2nd Session. V: 205-302.

(Forest Cover, Forest Openings, Forest Composition/ Snowpack, Snowmelt/Europe)

Zon reviewed early Russian studies concerned with the influences of several kinds of forest stands upon the accumulation and melting of snow. Quotations from Zon state:
"...broadleaf forest (birch 35 to 75 years old and oak 25 to 90 years old) will contain per acre about 41 percent more snow water than a pure pine forest (20 to 90 years old); 60 percent more than a pure spruce forest; or an average of about 50 percent more than coniferous forests in general .... Young pine stands contain 9 to 10 percent more snow than older pine stands (60 to 90 years old)... The important fact..., however, is that young forests, deciduous forests, and small openings within forests collect nearly twice as much snow as open fields, while dense, pure spruce forests contain less than open fields."
"...the period of snowmelting lasts within forests from 26 (1904) to 57 (1902) days, while snow in the open disappears within 6 or 7 days."
"... The snow disappears first of all from clearings in the forest, simultaneously with its disappearance from open fields. Next it disappears from young plantations, in which the tree tops have not yet begun to touch each other; then from thin oak forests on southerly slopes and old, open pine forests; then from dense stands of birch on northerly slopes; later from pine; and last of all from spruce...
"Thus, [Zon concludes p.36, 37] while compared with deciduous stands, coniferous forests, and especially pure dense spruce, prevent large accumulations of snow, their effect in retarding its melting, especially in the case of

spruce, is much greater, and for this reason they are more efficient in reducing the height of spring freshets."

Original not seen, cited from Colman (1953).